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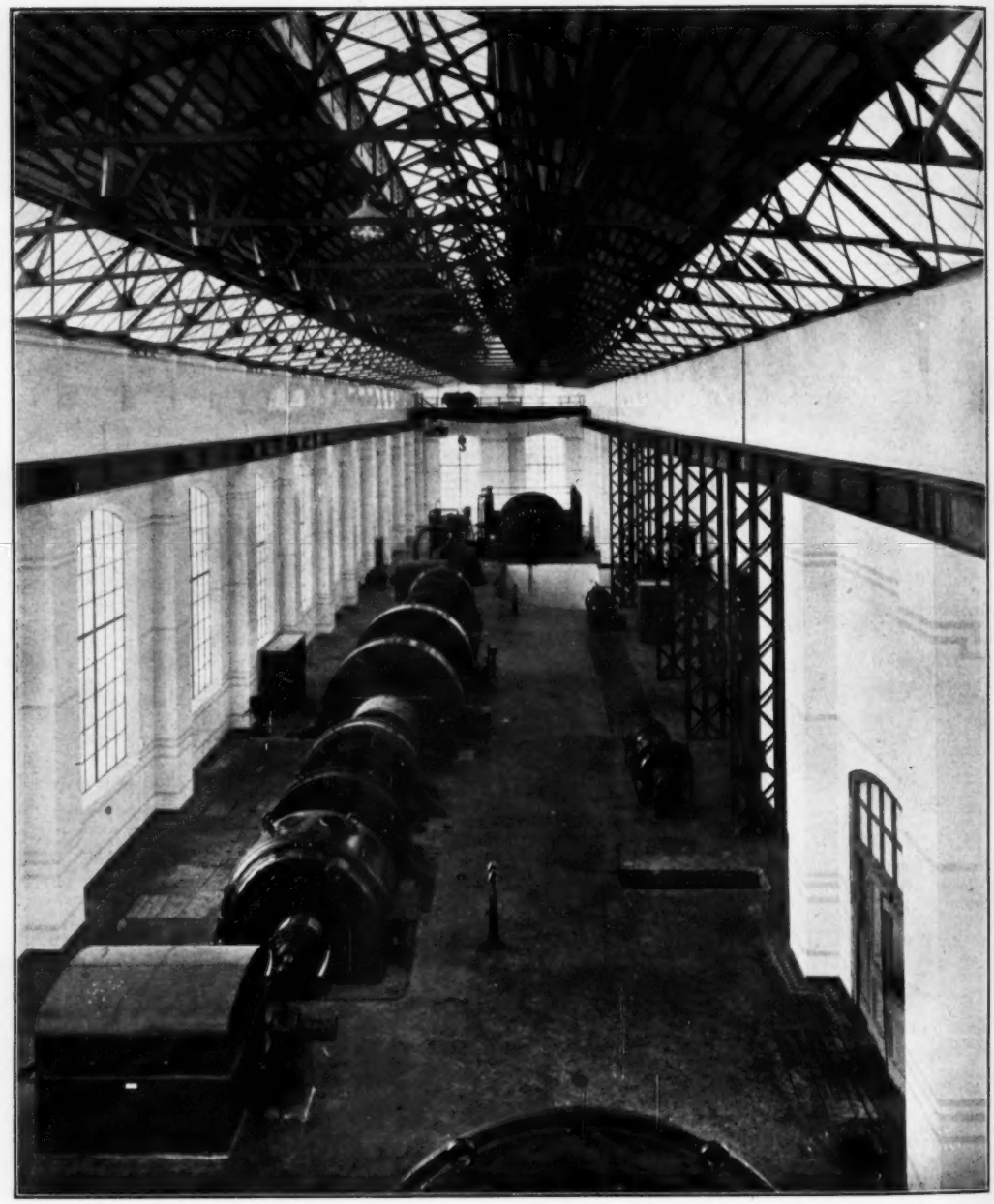

WINDING ENGINE HOUSE AT THE POWELL DUFFRYN STEAM COAL COMPANY'S BRITANNIA PIT, PENGAM, SOUTH WALES.

The English Electric Journal

Vol. 1. No. 6. APRIL, 1921. One Shilling.

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EDITORIAL.

All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, QUEEN'S HOUSE, KINGSWAY, LONDON, W.C.2.

THE YEAR'S WORK.

We print below an extract from the speech delivered by the Chairman of The English Electric Company, Sir Charles Ellis, G.B.E., K.C.B., at the Annual Meeting of the Company, which was held in London on April 27th :—

During the last year our principal task has been that of consolidating the Company's organisation. Satisfactory progress has been made in the adaptation of our Coventry Works and the restoration of the other factories to their normal activities, and we have proceeded with the least possible delay with the application of our fixed policy of devoting each Works to the manufacture of that class of machinery for which by reason of its lay-out and past history it is best adapted. It is obvious that the rapidity with which any such re-arrangement can be carried through must depend to a great extent on the contracts in course of execution at each Works ; but it is gratifying to be able

to record that, in spite of the volume of work in progress and the necessity of taking no action which would impair our power to meet commitments, substantial progress has, in fact, been made towards our ultimate scheme for the best possible utilization of our five Works. We recognize, however, that the successful working of any scheme depends above all on continuous teamwork by our staffs, not only in each Works, but between each Works and the rest. I cannot let pass this opportunity of acknowledging what we owe to those staffs. They have worked loyally and without losing their individuality in a corporate interest.

To return to the special functions of our Works, at Coventry we have manufactured turbine-electric units of very large sizes, rolling mill equipments, and the larger classes of engineering products. Preston has for long been well-known as an important centre of traction work ; it has now specialised even more completely in that branch of the industry, and at the present time electric locomotives, in addition to all forms of electrical traction equipment, are being manufactured there. At Rugby and Stafford the manufacture respectively of the medium sizes of steam turbines and of electrical generating and industrial machinery has been further developed. The Bradford Works, which have been specially laid out for the smaller range of industrial motors, have now, in addition, their own machine moulding foundry.

Like all other engineering firms, we were dogged throughout 1920 by the unfortunate effects of the Moulders' Strike, which began in 1919 and was protracted into the early part of the year, but in recent months there has been a welcome improvement in the foundry position. We have been able to enlarge and improve the foundry capacity of our own Works, and thus to become to a greater extent independent of outside suppliers.

Our business both at home and abroad was well maintained up to the later months of the year, but the general depression which began to affect the steel and kindred industries in the early autumn became noticeable in the electrical trade a little later. We have fortunately, a considerable order book still to be executed, and it is not unreasonable to hope that in all except the smaller classes of our manufactures the flywheel action of this volume of orders will be sufficient to carry us over until trade revives. I referred a year ago to the importance of railway electrification proposals for the future of the electrical industry. Since then little progress has been made with the electrification of railways in the United Kingdom ; but the delay is due mainly to difficulties of finance, and the technical advantages of electrification are not in dispute. In this connection it will be of interest to you to learn that the execution of the contract which the Company obtained last year from the New Zealand Government for the electrification of the Arthur's Pass

section of the Midland Railway of New Zealand is proceeding satisfactorily.

Amongst the problems to which the Board has devoted its most anxious attention has been the enforcement of economy in selling expenses at home and abroad. To this end I am glad to report that our working arrangement with Siemens Bros. & Co., Ltd., to which I referred last year, has been followed by the formation of the English Electric & Siemens Supplies, Ltd. This Company (the capital of which is held by Messrs. Siemens and ourselves in equal parts) will deal exclusively with marketing the minor products of the two concerns and electrical supplies generally. It has taken over our former subsidiary Company, the English Electric Supplies, Ltd., together with a section of the selling organisation of Messrs. Siemens, and should effect a definite saving in that side of our work.

If we look at the labour position, I should wish to say, in the first place, that we as a firm have no complaint to make as to the manner in which our workmen have settled down to work. They have worked hard and well; and through their ready co-operation on our Works' Committees our differences of view have been brought to light as soon as they have arisen, and have shown themselves in all cases susceptible to treatment by a full and frank discussion. None the less, it is certain that the cost of production in British engineering, and even more those in the industries from which we draw our materials, have led and are leading to the loss of many important contracts in world competition. Our raw materials are to a large extent the highly-finished products of our suppliers; and if we are to extend or even fully to regain our pre-war business abroad, considerable reductions will be necessary in the price of those products, and therefore in the cost of the whole range of processes through which they are built up from the basic materials of coal and iron. How these reductions are to be brought about in a perfectly fair way I do not propose to discuss here, but I have no doubt whatever that we shall be able to meet the crisis if both employers and workers can be sure that the necessary sacrifices are distributed as fairly and equitably as is humanly possible possible over all those concerned.

The immediate future must be an anxious time for every industry. Apart from wages and all questions of internal organisation, every industry has to-day to reckon with factors which are essentially political and, therefore, beyond its control, yet which exercise a profound influence on the whole system of international trade. We can, however, say this with confidence, that whether a revival of trade comes soon or late—and that it will come sooner or later no one can doubt—the electrical industry has an assured future, because it is bound up with those improvements and economies in productive organisation which we all, I think, regard as a necessary element in the future prosperity of the world.

Electric Winders.

By J. KIRKWOOD, B.Sc., A.M.I.E.E.

The rapid strides made during recent times in the introduction of electric winders into collieries and other places where winding hoists are used, lead us to believe that the time is not far distant when all winding will be performed electrically. Well over 100 electric winding engines are already in successful operation in this country, and the reliability and economical working of this type of plant has been proved beyond dispute. In this article we propose to deal with only two systems of electric winding, the alternating current system, in which the drum is driven by a 3-phase induction motor, and the Ward Leonard system, in which the drum is driven by a D.C. motor which receives its power from a separate converter set.

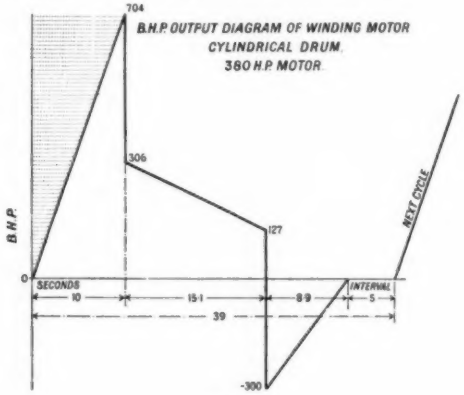

FIG. 1.

The demands put upon the winding motor when in operation are typically illustrated by the winding diagrams given in Figs. 1, 2 and 3. Fig. 1 shows the B.H.P. output of a winding motor employing a cylindrical drum without the use of a balance rope. This is the most common arrangement, and the first to be introduced, but it will be seen from the diagram that the peak load is very high compared with the average, and when a colliery has to supply its own electric power, this peak load might have such an adverse effect on the supply as to necessitate an increase in the capacity of the station. To overcome this difficulty some means had to be adopted to reduce the peak load. Two of the methods are those illustrated by the diagrams in Figs. 2 and 3. Fig. 2 shows the B.H.P. output of a winding motor with a cylindrical drum, when a balance or tail rope has been introduced. This rope is joined to the bottoms of both cages, as shown in Fig. 2A. Although, by its use, the weights to be accelerated are increased, yet, by counterbalancing the weight of the hoisting rope at the beginning of the wind, the net result is to reduce the starting torque and consequently the peak load on the motor. The balance rope has not been very popular with colliery engineers in this country in the past, but this is probably due to the harmful effect caused by the "whip" or "swing" of the rope produced in the older type of steam winders. With the electric drive,

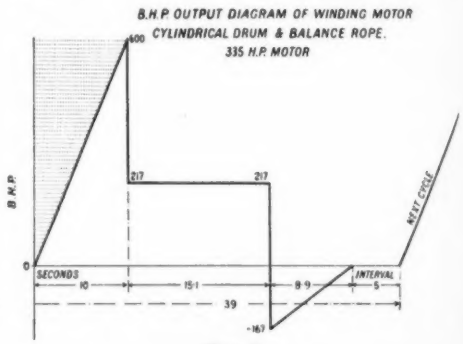

FIG. 2.

however, owing to the even turning moment, the balance rope undergoes practically no lateral movement, and there are many examples in which the balance rope is used with electric winders with complete success even in the deepest of shafts.

Another method frequently adopted of reducing the peak load at the beginning of the wind is by the use of a cylindro-conical drum, a typical winding diagram for which is given in Fig. 3, the drum itself being shown diagrammatically in Fig. 4. It consists essentially of a central

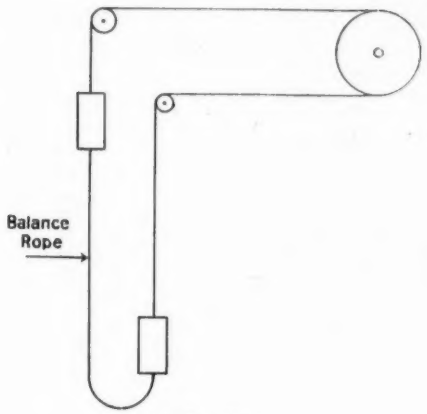

FIG. 2a.

drum of large diameter, with two lateral drums of smaller diameter, the connections between the different sized drums being effected by means of conical connecting pieces, as shown. The principle of this type of drum is that at the start of the wind the ascending rope with its loaded cage is on the minimum diameter, whilst the descending one with its unloaded cage is on the maximum diameter. In this way the counter-balancing effect of the descending cage is greatly increased and, in fact, may be such that the resultant static moment during the starting period may be zero, although this is unusual, as it would necessitate too great a maximum diameter. In deciding on the winding programme, it is generally arranged that the acceleration of the drum, motor and descending load be completed on the number of live turns on the minimum diameter, during which time

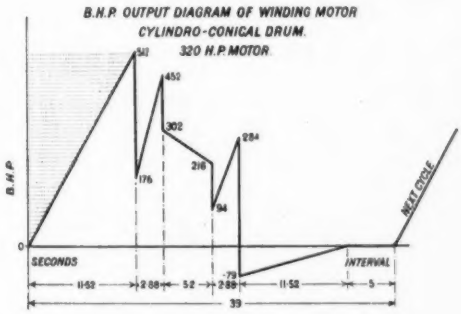

FIG. 3.

the resultant static moment is at a minimum, thus reducing the peak load during the acceleration period. An advantage is also gained at the end of the wind, owing to the fact that the ascending load is on the maximum diameter, and the descending load on the minimum diameter. The resultant static moment is then greatly increased, and the kinetic energy of the moving masses can be used to help the completion of the wind, thus increasing the efficiency of the plant.

The cylindrical drum with tail or balance rope is not always so efficient as the cylindro-conical drum, but is frequently adopted when the cylindro-conical drum would be unsuitable. Such a case would occur when the cage had several decks, and separate decking was necessary.

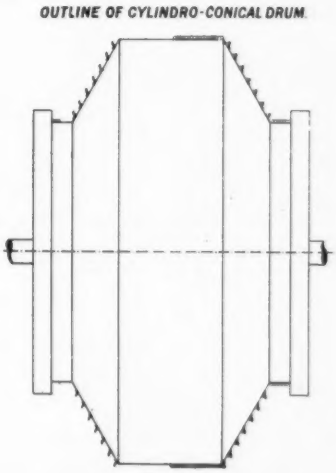

FIG. 4.

Other methods by which the peak load at the beginning of the wind may be reduced are the pure conical drum, the reel or bobbin winder, and the Koepe pulley. The pure conical drum is seldom used in electric winding, as it shows no advantage over the cylindro-conical type, and is heavier and more costly. In principle, the reel or bobbin winder, which is used with a flat rope, is good, as, owing to the light construction of the bobbins, the power required to accelerate them is not nearly so great as that of the drum winder; but difficulties have been experienced with the manufacture of flat ropes, and it is

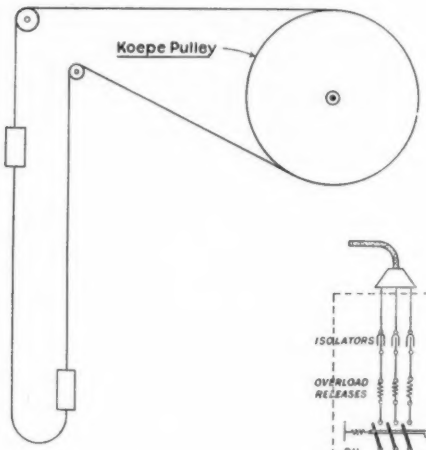

FIG. 5.

therefore practically obsolete in this country, though still being used quite considerably on the Continent.

Brief mention should be made of the Koepe pulley, which consists essentially of a large diameter pulley containing a V-shaped groove running around the centre of its rim. It is used as shown diagrammatically in Fig. 5. A single rope lies in the groove, making contact over less than the full circumference, and each end of the rope, after passing over the necessary guide pulleys, is attached to a cage. The drive is effected by the friction between the pulley and the rope.

The chief disadvantages of this pulley are (1) the tendency of the rope to slip, (2) unsuitability for working different levels, (3) the special means which have to be adopted for re-capping the rope from time to time, and (4) that if the rope breaks both cages are detached from the winder The tendency to slip introduces the absolute necessity for a balance rope in this case, otherwise the pull of the unbalanced ascending rope would be so great that the rope would slip Even with a balance rope, the difference in static pull on the two sides of the rope is limited, as is also the rate of acceleration. The last objection

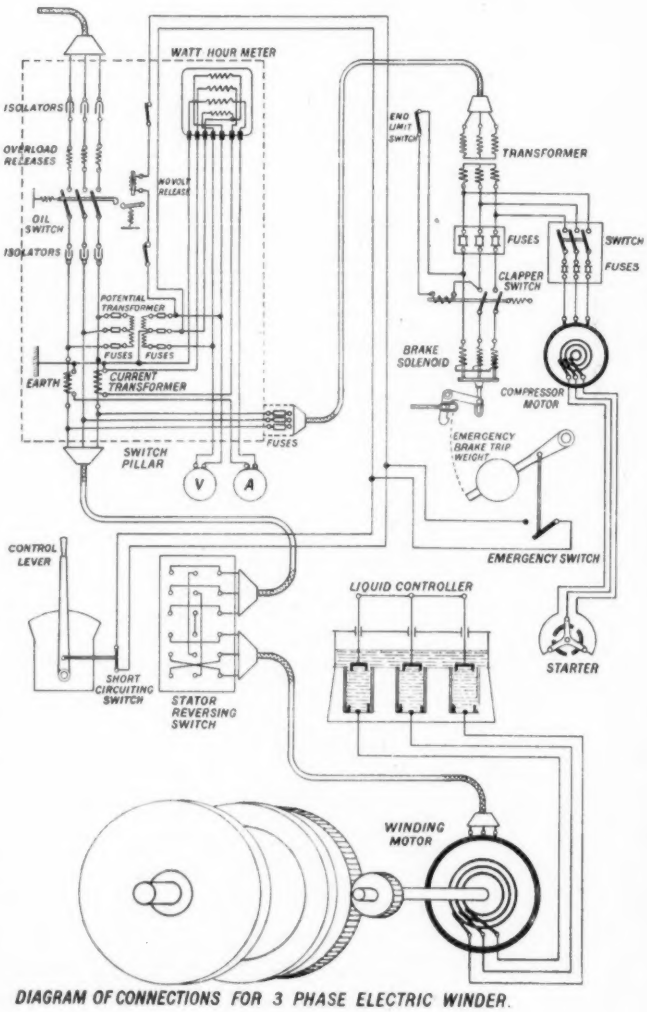

DIAGRAM OF CONNECTIONS FOR 3 PHASE ELECTRIC WINDER.

FIG. 6.

mentioned above is largely overrated, as in the case of a Koepe pulley the possibility of a breakage is infinitely less than with any other system, for if any excessive load should come on to either end of the rope, the rope would simply slip instead of breaking. The great advantage of the Koepe pulley is the small amount of inertia which has to be overcome as compared with that of a drum, which ensures more economical winding. It is also suitable where the space available is so limited as to prohibit the use of a drum winder of ordinary dimensions.

The disadvantages of the Koepe pulley have, however, prevented it from making much progress in this country, although it is used to a considerable extent on the Continent.

THE ALTERNATING CURRENT SYSTEM.

In the A.C.—or 3-phase—system an asynchronous motor is used either coupled direct, or more frequently through gearing, to the drum shaft. Owing to difficulties experienced in the building of small 3-phase induction motors for low speeds, direct coupling of the motor to the drum shaft is, as a rule, only possible for large winders. Low speed induction motors, however, have a much lower efficiency and lower power factor than high-speed motors, and, since the introduction of reliable machine-cut double helical gearing of efficiencies of 95 per cent. to 98 per cent., practically all 3-phase winders now installed are gear driven. Fig. 6 shows a typical diagram of connections for a 3-phase winder. Power is supplied direct to the stator through an automatic oil switch with one no-volt and

DIAGRAMMATIC ARRANGEMENT OF CONTROL GEAR.

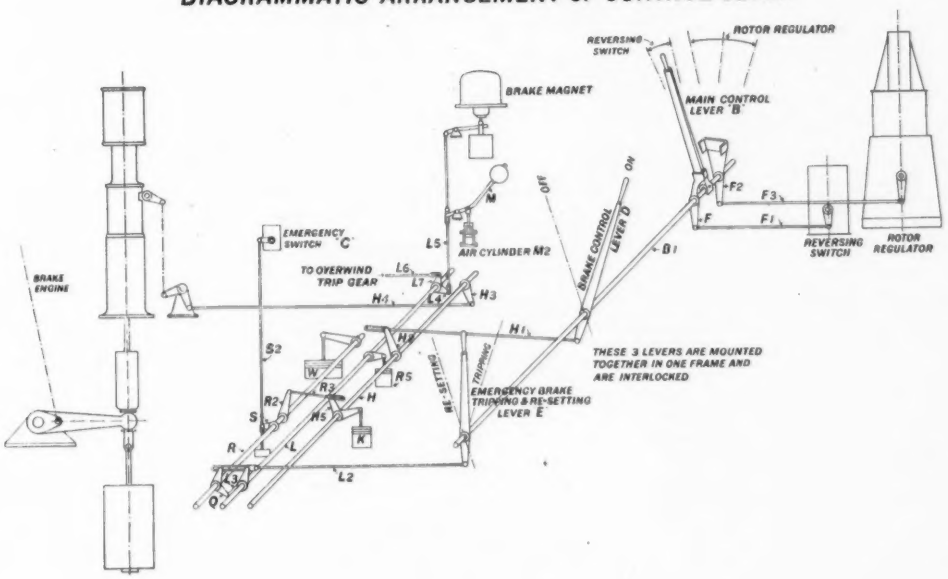

FIG. 7

either two or three overload releases. The circuit also contains a stator reversing switch, which, in the case of a high tension supply, may have a buffer resistance to damp down excess voltages during switching operations. Fig. 7 shows a diagrammatic representation of the control gear on a 3-phase winder.

The starting up and speed regulation is performed by means of a resistance in the rotor circuit. For winders of more than 200 H.P. or so this resistance is of the liquid type, while for smaller winders the metallic resistance is employed. The reversal of motion is obtained by a reversing switch in the stator circuit. The operations of starting and reversing are carried out by the same lever. In the mid position the supply is cut off. A forward motion from this position closes the stator reversing switch to give rotation of the motor in one direction, while a backward motion gives rotation in the opposite direction. The continuance of the movement of the control lever in either direction cuts out the resistance of the rotor circuit and brings the motor up to speed.

The shaded portion in Fig. 1 shows the energy dissipated in the controller during the acceleration period (neglecting motor losses). This is the factor which exercises the greatest effect in fixing the overall efficiency of the plant. If this peak load is high, and the frequency of wind high, the efficiency will be low.

This speed regulation of an induction motor by means of additional resistance in the rotor circuit is one of the weak points of the A.C. system. Another is that the speed of an induction motor varies not only with the resistance in the rotor circuit, but also with the torque it is exerting. Hence, a certain amount of skill is required on the part of the driver to wind to the same diagram with different loads. Therefore, although one may limit the speed to within a certain definite maximum value by means of an overspeed device which applies the emergency brake, in the event of this maximum speed being exceeded, one cannot have automatic control,

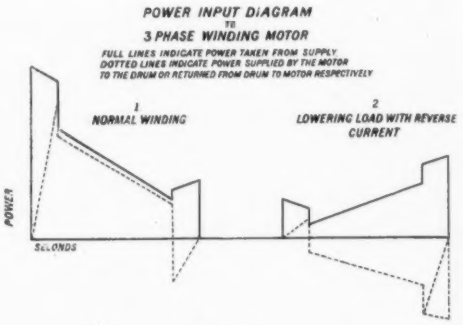

FIG. 8.

since the operation of the control lever in any particular way will give a different acceleration and retardation for each different load.

Another disadvantage of the A.C. system of winding is concerned with the method of braking when lowering loads. This can be carried out in four ways: (1) by means of mechanical brakes; (2) by lowering at a speed above the synchronous speed of the motor, so that the motor runs as an asynchronous generator and pays back energy to the line; (3) by countercurrent braking, that is, by reversing the stator connections so that the torque of the motor is in opposition to the direction of rotation which is then produced by the descending load; (4) by means of an eddy-current brake.

Only one of these methods is regenerative, and that is the second method, which is, however, difficult to control, and is only effective above synchronous speed. Hence, this method cannot be used to bring the cages to rest; this must be done by means of mechanical or countercurrent braking. It is not at all suitable for use on ordinary winding engines, where the time available for the wind is limited and simple and effective braking absolutely necessary. It might, however, be recommended for long, slope haulages, where there is ample time to execute the various movements.

FIG. 9.

Countercurrent braking is most commonly used, since it is the most easy to control, but it is extremely wasteful (see Fig. 8), as not only is it impossible to regenerate the power developed by the descending load, but power is actually drawn from the line to counteract it. The power taken from the line, as well as the power developed by the descending load, is dissipated in the controller. Hence larger controllers are required than would be necessary under normal coal-winding conditions.

Frequent mechanical braking places too great a wear and tear on the brakes, and necessitates special precautions to dissipate the heat generated and to prevent the burning of the brake blocks.

The eddy-current brake consists of an ordinary D.C. field revolving inside a water-cooled hollow iron casting. It is costly, particularly if the D.C. supply has to be specially installed for the field, and has the disadvantage that it cannot bring the winder to rest. To do this the mechanical brakes must be used.

Fig. 9 is an example of an A.C. winder with direct-coupled winding motor, installed at the Harton Colliery, South Shields. This plant is capable of dealing with an output of about 207 tons per hour from a depth of 1,424 ft., the net weight per lift being 4·2 tons and the maximum rope speed 41 feet per second. The drum is of the cylindrical type, 14 ft. diameter by 8 ft. wide between the flanges. The motor is connected direct to a 5,500-volt 40-cycle supply, and its rating is 950–1,700 B.H.P. at a maximum synchronous speed of 60 R.P.M.

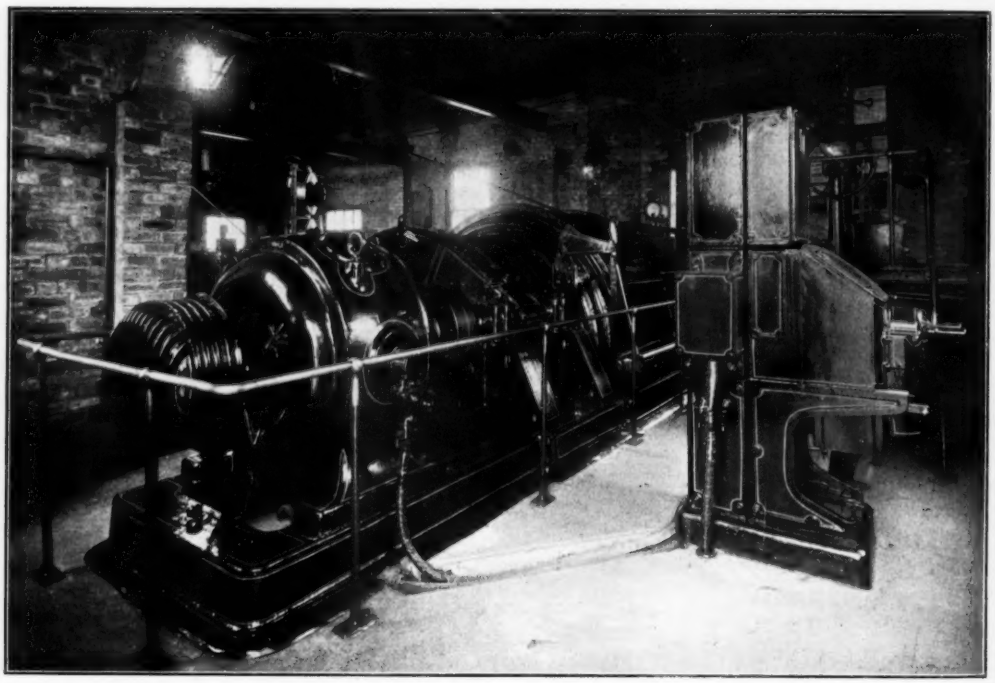

FIG. 10.

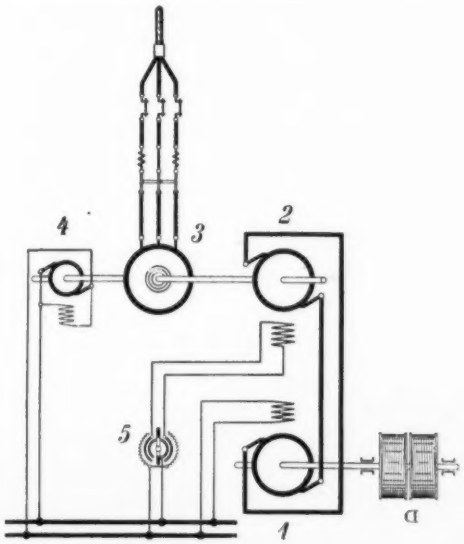

FIG. 11.

Fig. 10 is an example of an A.C. winder with geared winding motor installed at Messrs. Pease & Partners' John Henry Pit, Durham. This plant is capable of dealing with 70 tons per hour from a depth of 625 ft., the net weight per lift being 1 ton, and the maximum rope speed 20·2 ft. per second. The drum is of the cylindro-conical type, 6 ft. minimum to 9 ft. maximum diameter, the maximum drum speed being 42·9 R.P.M. The motor is connected to a 2,750-volt 40-cycle supply, and has a normal output of 96 B.H.P. at a synchronous speed of 400 R.P.M.

THE WARD LEONARD SYSTEM.

Many of the disadvantages of the A.C. system disappear with the installation of some form of regenerative system. One of the most popular of these is illustrated in Fig. 11, and is known as the Ward Leonard system of control.

The Ward Leonard system is based on the fact that the speed of a separately excited D.C. motor is directly proportional to the voltage applied to the armature. If, therefore, the D.C. motor (1) is used to drive the drum D, it can be made to run at any desired speed and in either direction of rotation, by varying the voltage and direction of the current impressed on the armature. This D.C. power is obtained from a separate generator (2), known as the variable voltage generator, and driven at constant speed by a motor (3) connected to the supply mains. The variable voltage generator and its driving motor are coupled together and

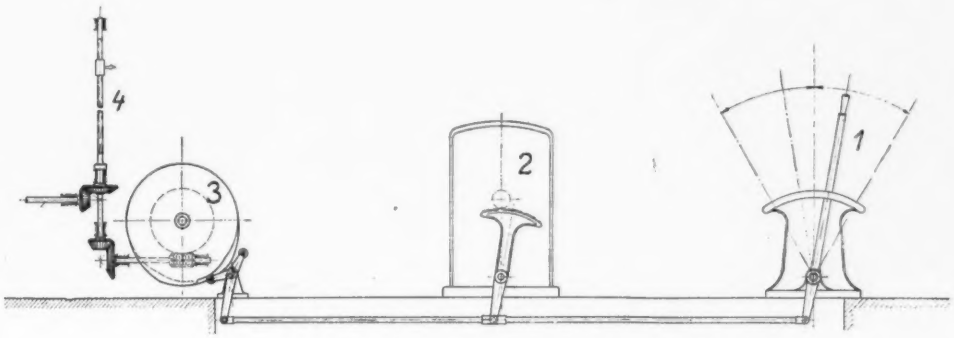

FIG. 12

DIAGRAM OF THE SIEMENS DEPTH INDICATOR WITH SAFETY DEVICE.

(1) Operating Lever. (2) Controller. (3) Control Cam. (4) Depth Indicator.

mounted on a common bedplate, which also carries, on the same shaft as the other two machines, a small D.C. generator. This generator supplies the excitation current to the variable voltage generator and the winding motor, the triple combination being known as the converter set.

A regulator (5) is used to vary the field of the V.V. generator and, consequently, its voltage, between O and a ± maximum, and in this way the speed of the winding motor to which this voltage is applied can also be varied between zero and ± maximum.

The principal feature of the control is that the speed and direction of rotation of the winding motor are determined solely by the regulator or, in other words, by the position of the driver's control lever. For all practical purposes this holds true whatever the load in the cage may be, and whether the load is being raised or lowered. When in a running position—by moving the control lever towards the " off " position—a strong electrical braking effect is obtained, as the motor then acts as a generator, and returns energy through the converter set to the line. The same electrical braking effect can be obtained when lowering loads, and the low speeds required for inspection tests can be readily obtained by a slight movement of the lever from the " off " position.

It should be noted that the controller only deals with the field of the V.V. generator (about 2 to 3 per cent. of the output), consequently, it is very small as compared with an A.C. controller, and can be readily operated even on the largest winders without the use of auxiliary gear.

DIAGRAMMATIC ARRANGEMENT OF CONTROL GEAR.

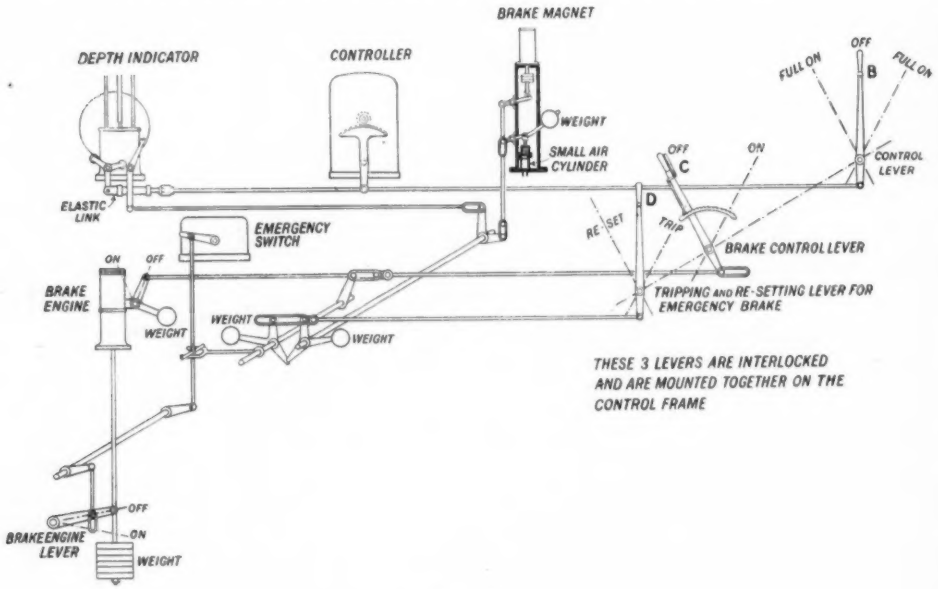

FIG. 13.

As any given position of the control lever corresponds to one speed only, and one direction of rotation, it is possible to provide simple safety appliances of absolute reliability.

Fig. 12 shows diagrammatically the Siemens system for the automatic control of the acceleration and retardation.

The spindle of the depth indicator drives two cam wheels, one for each cage, through gearing proportioned so that the wheels make nearly one complete revolution. Each wheel has two cams, one for acceleration and one for deceleration. When starting, the control lever can only be moved from its mid position at a rate determined by the shape of the cams, which shape is designed to give the predetermined rate of acceleration. This rate cannot be exceeded. When retardation should begin, if the driver has not already started to bring back his lever, the deceleration cam gradually forces the lever back

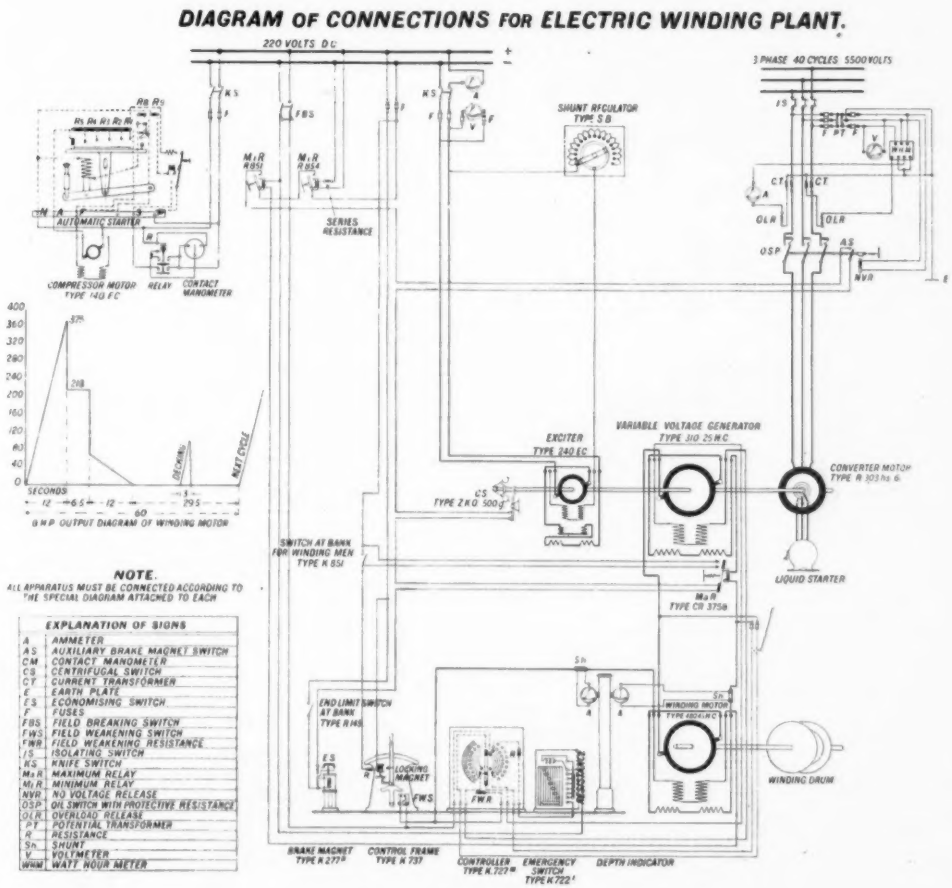

FIG. 14.

to the " off " position. Acceleration, retardation, and speed of wind are thus within the driver's control, provided he does not attempt to exceed the limits for which the cams are designed.

In the event of an overspeed, electric braking automatically takes place. The winding motor will act as a generator and supply power to the V.V. generator, which will then act as a motor driving the set above synchronous speed, causing the induction motor to act as an asynchronous generator and pay back power to the line, Should the speed of the set exceed a predetermined maximum, a centrifugal switch driven from the shaft of the set will open the circuit of the brake magnet and apply the emergency brake. Fig. 13 shows a diagrammatic representation of the control gear.

With the Ward Leonard system, it is also possible to limit, without difficulty, the maximum speed when winding men. To do this a locking magnet is fitted in the driver's control frame and actuated by a switch at bank, which switch, when closed, energises the locking magnet and interposes a barrier in the way of the control lever so that it can only be moved the required amount.

Fig. 14 shows a typical diagram of connections with Ward Leonard control and a typical diagram of the energy consumption for this will be seen in Fig. 18. It will be noticed that the power demand on the supply rises slowly till it reaches a maximum value at the end of the acceleration period. For this reason, it might be possible to instal a Ward Leonard winder where an A.C. winder could not be permitted, despite the somewhat smaller

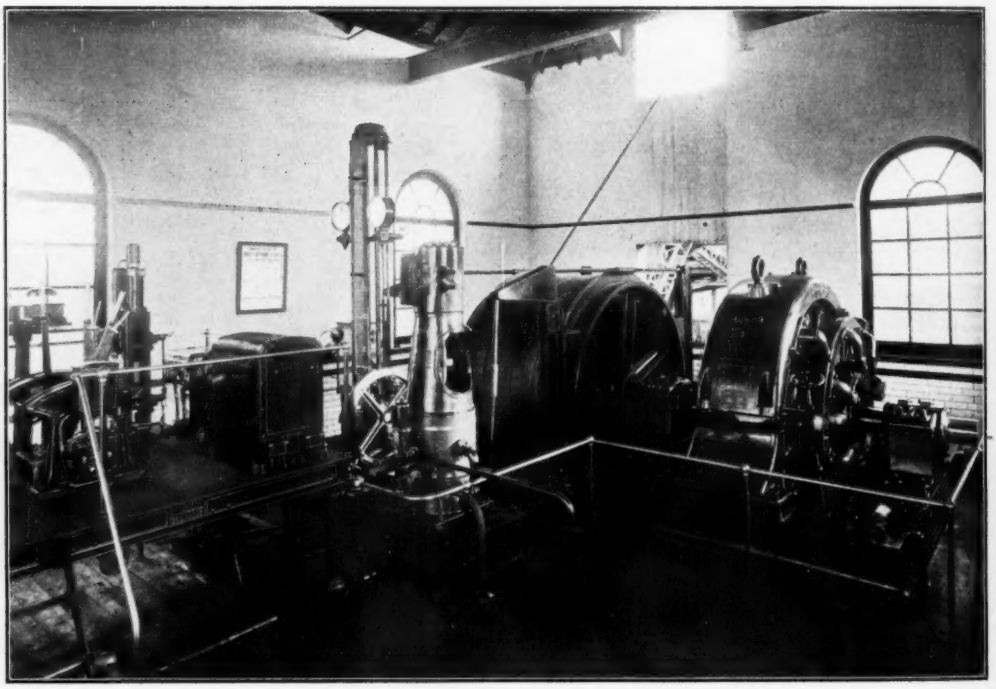

FIG. 15.

peak load, owing to the peak load with the A.C. winder coming on suddenly and lasting the whole of the acceleration period. Also the energy consumption when decking, when the winding motor speed is very low, is practically negligible.

It will also be seen that during the acceleration period there are no rheostatic losses such as take place in the controller of the A.C. winder. This, however, is somewhat counterbalanced by the conversion losses in the set and also by the running losses in the set during the decking period. Consequently, if the decking period is long, it may happen that the total energy consumption with the Ward Leonard control is greater than with the A.C. control. It is not possible to say that one system is more efficient than the other until the K.W. input diagrams have been compared. As stated before, with Ward Leonard control, all braking, including the lowering of loads, is done regeneratively, and if there is much of this to be done, there is no question as to which is the more economical scheme.

Fig. 15 is an example of a D.C. winder with Ward Leonard control installed at Messrs. The Lambton & Hetton Colliery Company's Lumley Sixth Pit, Durham.

Fig. 16 shows the Ward Leonard Converter Set.

The plant is capable of dealing with 102 tons per hour from a depth of 480 ft., the net weight per lift being 34 cwts., and the maximum rope speed 26·6 ft. per second. The drum is of the cylindrical type, 8 ft. diameter by 4 ft. wide,

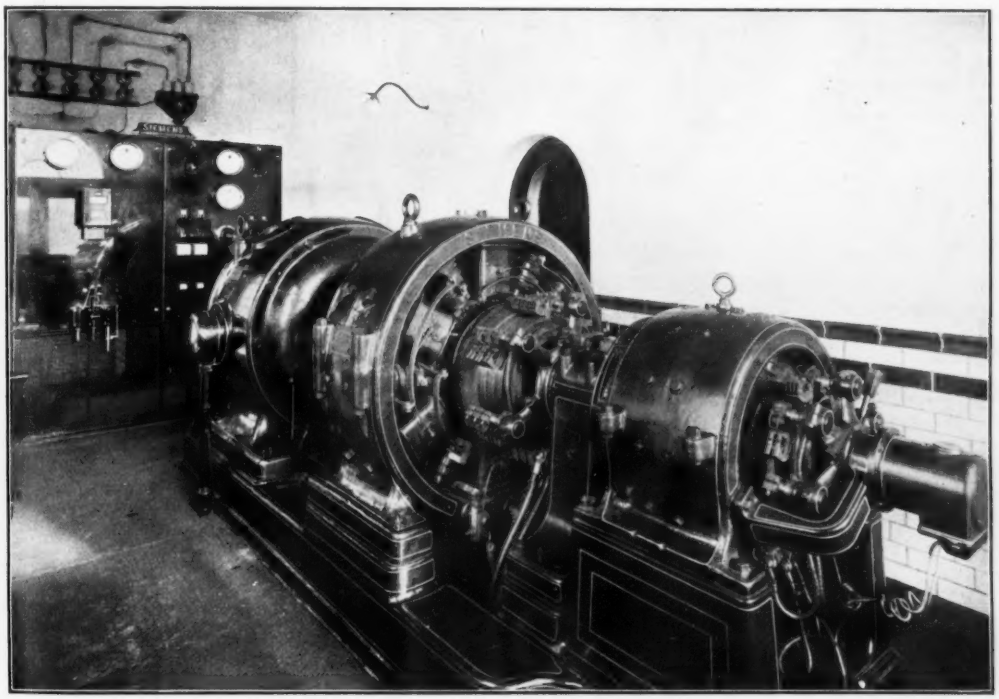

FIG. 16.

and is direct-coupled to the winding motor, which has a normal rating of 187 B.H.P. at 63 R.P.M.

In order to compare the relative merits of the two systems, the following points must be taken into consideration :—

1. *Initial Cost.*—The initial cost of A.C. control is less than that for the Ward Leonard system. With a medium-sized gear-driven plant dealing with, say, 180 tons per hour, from a depth of 750 ft. and a net weight per lift of three tons, the A.C. system may cost 30 to 35 per cent. less initially than the Ward Leonard plant. The A.C winder also occupies much less space, and can therefore be accommodated in a smaller building.

For plants for export the advantage is also with the A.C. system, as the total weight is always considerably less than that of a Ward Leonard installation, and this will considerably reduce the freight charges and also transport troubles where the site is difficult of access.

2. *Regulating Ability.*—The regulation of the Ward Leonard control is much more convenient than that of the A.C. winder, particularly for winding men, and for shaft and rope inspection. Moreover, with the A.C. control all speed variation entails rheostatic losses, which become especially noticeable when much lowering and braking takes place. Since the A.C. controller has to control the main current used, and the Ward Leonard only the exciting current of the D.C. generator, the regulator for the latter system can be smaller and cheaper in construction than that for the former.

Finally, the Ward Leonard system is more adaptable and lends itself in a greater degree to the adoption of safety devices.

3. *Influence on the Power Station.*—With the Ward Leonard system, the peak load, though slightly greater than that of the A.C. system, comes on gradually and is only of very short duration, whereas the A.C. peak load comes on immediately at the beginning of the wind, and lasts during the whole of the acceleration period.

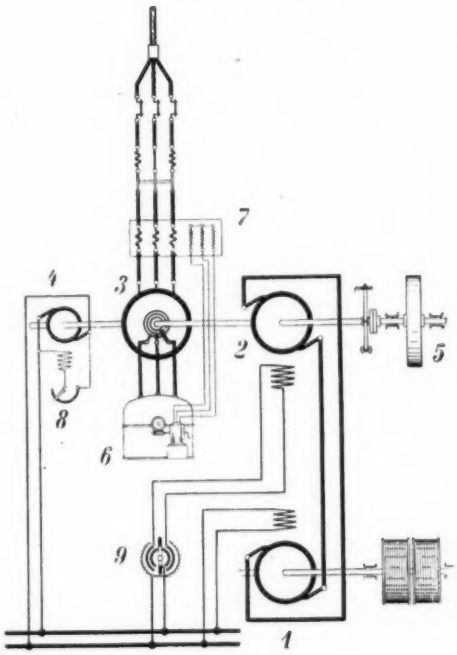

FIG. 17.

4. *Economy.*—Generally speaking, the actual running costs of the A.C. plant are less than those of the Ward Leonard system, but where much winding at reduced speed and lowering of loads takes place, the difference of energy consumption in favour of the Ward Leonard system will probably render this the more economical in the long run.

5. *Working Safety.*—Here the advantage lies with the Ward Leonard system, owing to the very adequate safety devices which can be used.

No attention has been given in this article to the problem of equalising or levelling out the winding motor peak loads. Roughly speaking, this is generally carried out by means of a heavy flywheel direct coupled to the Ward Leonard

converter set as illustrated in Fig. 17. On periods of overloads the speed of this flywheel is automatically reduced to a predetermined value, the stored energy corresponding to this speed reduction being utilized to equalise the load on the supply, and during intervals between winds, the wheel is again brought up to speed. In general, it may be said that unless an equaliser is absolutely necessary, owing to the inability of the power supply conveniently to stand the effects of the peak loads, it should be avoided, since the overall efficiency of the installation will be less than the pure Ward Leonard owing to the additional losses due to the flywheel and the automatic slip regulator. In the case previously quoted, of a winder dealing with 180 tons per hour from 750 ft. with a net weight per lift of three tons, Fig. 18 shows the B.H.P. output diagram of the winding motor and approximate K.W. demand on the supply for the A.C., W.L., and equalising system—of the Ilgner type—respectively. The energy consumption per wind and the overall efficiency for each of these winds would be :—

	Energy Consumption per wind.	Overall Efficiency.
A.C.	3·63 B.O.T. units	52·5%
Ward Leonard ..	3·75 „ „	51·0%
Ilgner	4·22 „ „	45·2%

A true comparison, however, cannot be made without taking into account the effect on the power system as a whole.

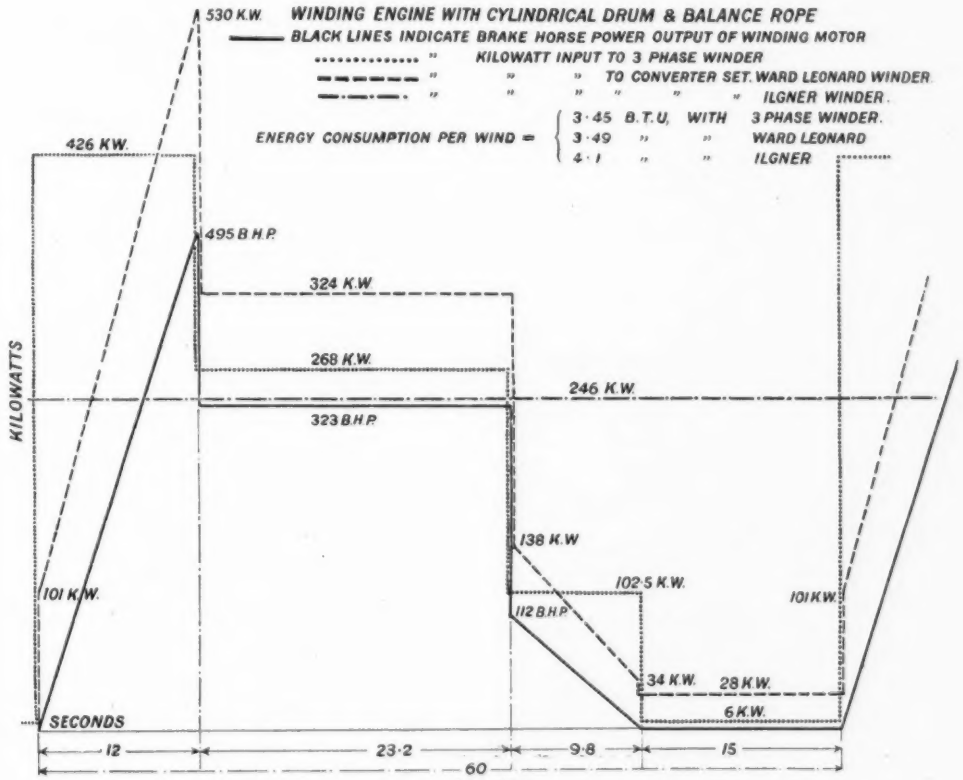

FIG. 18.

One great point in favour of the equalising system is that the flywheel forms a temporary reserve of power which makes it possible to complete a wind which has just begun, or is under way, should the power supply fail

Figs. 19 and 20 illustrate one of two winders on the Siemens-Ilgner System installed at the Powell Duffryn Steam Coal Company's Britannia Pit, Pengam, South Wales.

Fig. 19 shows the initial cylindrical construction of the drum 14 ft. diameter as used during sinking operations, and Fig. 20 the final construction as a cylindro-conical drum 14 ft. to 22 ft. diameter for coal winding conditions. It will be noticed in Fig. 19 that the driver's platform is enclosed by sheet metal with observation window in the front.

The frontispiece to this number of the Journal shows the double flywheel converter set at the Britannia Pit, with the other winding engine in the background.

Each of the winding engines is capable of dealing with an output of 360 tons per hour from a depth of 2,190 ft., with a net weight per lift of 6 tons and a maximum rope speed of 72 ft. per second.

FIG. 19.

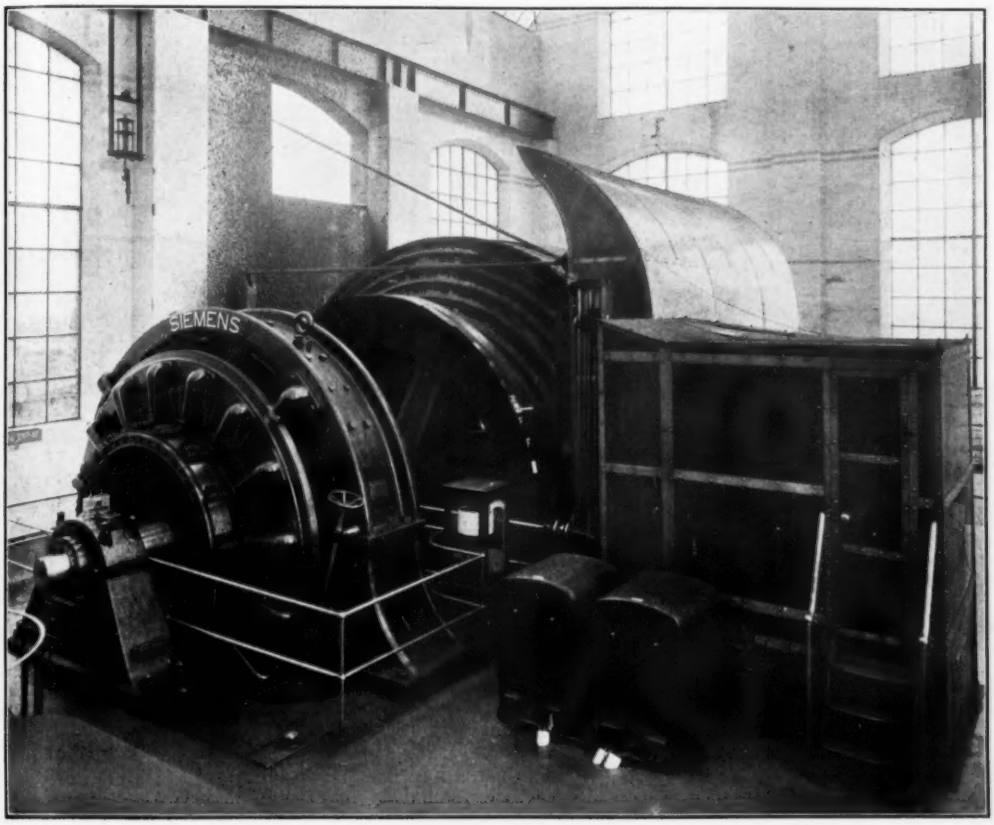

FIG. 20.

Each winding arm is direct-coupled to two motors, one at each end, each motor having a normal rating of 1,300 B.H.P. and maximum 2,160 B.H.P. at 62·8 R.P.M.

The two flywheel sets, one for each winder, each consist of an induction motor, two continuous current generators, and a 30-ton solid steel flywheel running at a synchronous speed of 500 R.P.M. on a 10,000-volt 50 cycle supply.

The two sets are placed in line and can be coupled together, so that when the two winding engines are working, each set will assist in dealing with the peak loads of the other. Further couplings are provided between each set and its flywheel, which enable the plant to be run in any of the following ways :—One set with two flywheels and one set without flywheels, either set at the same time with one flywheel or without a flywheel, or the whole coupled up together. In addition, a change-over board is provided to enable either set to work either winding engine.

[This article is based on a lecture given by the author before a joint meeting of the Association of Mining Electrical Engineers and The Institution of Electrical Engineers, at Sheffield, on March 20th, 1920.]

The Modern Steam Condenser.

By E. R. BRIGGS, M.Inst.C.E., M.I.Mech.E.

The evolution of the Modern Steam Condenser has been almost entirely on practical lines. The theory of surface condensation has failed to keep pace with the demands of present-day requirements. This is due mainly to the great difficulty and cost of experimental work on condensers of sufficient size and under sufficiently varying conditions to give the necessary data to determine the actual laws of condensation. There is every reason to believe that these laws are exceedingly complex, and can only be determined by carrying out tests through a much greater range of conditions than is possible on any surface condenser in actual commercial operation.

The manufacture of Condensing Plants was first taken up by the Willans Works of the English Electric Company in 1903, and since that time a very considerable number of condensers have been designed and manufactured. This period corresponds with that of the development of the Steam Turbine for Central Power Stations. While the vast bulk of these condensers have been used for the company's own turbines, no small number have been installed for other makes.

During this period the development of the design has been continuous, every improvement that could suggest itself has been tried in actual conditions, and every advance in knowledge on the subject has been carefully reviewed with reference to its bearing on improving the efficiency of this portion of the Steam Power Plant.

The principal factors entering into the design of a Surface Condensing Plant are the following:

The mean temperature difference between the steam on the outside and the water on the inside of the tubes. The steam temperature may be considered as constant; the temperature of the water, however, increases as the heat is transferred from the steam to the water. Although the arithmetical mean is sometimes taken, it is more usual to use the logarithmic mean. If θ_1 is the temperature difference between the inlet water and the steam, and θ_2 that between the outlet water and the steam, then the mean temperature difference is—

$$\theta_m = \frac{\theta_1 - \theta_2}{\log_e \frac{\theta_1}{\theta_2}}$$

The initial difference, θ_1, varies from 20°F. to 30°F. For cooling tower conditions, where the inlet water is about 80°F., θ_1 may be taken as low as 20°F., and for practical purposes this is the economical minimum. It is better, however, to take 22°F. or 23°F., as the cost of pumping and the capital cost of the increased plant required tends to balance the decrease in steam consumption due to any further reduction in θ_1, and tends also to increase the overall station costs. For colder water, θ_1 should be increased slightly to, say, 26°F. or 30°F. for 50°F. inlet water. The outlet temperature difference, θ_2, that is, the difference between the temperatures of the steam in the condenser and the cooling water as it leaves, usually has a minimum value of 8°F. when θ_1 is about 20°F., increasing to 10°F. or even 12°F. for higher values of θ_1.

When designing surface condensers, it is usual to assume the rate of heat transmission as directly proportional to θ_m. The temperature range over which condensers work is too small to ascertain from experiments on them whether this is correct, or not, but the error is probably small. It is, however, known that the rate of heat transmission, K, varies with the temperature.

The velocity of the cooling water in the tubes materially affects the rate of heat transmission, K; this is usually written—

$$K = C\,v$$

where K is the heat transmitted in B.Th.U. per square foot of surface, per degree Fahr. difference per hour; C is a constant; v is the velocity of the cooling water through the tubes in feet per second; the index n is variously taken from 0·33 to 0·82. While 0·5 is the most commonly used value of n, it is probable that the actual value for surface condensers is lower. Most of the experiments from which the above values were determined were made under different conditions from those which apply to

actual condensers. Present-day practice is to use velocities of 5 to 6 ft. per second for the cooling water through the tubes. Since the pumping head increases with the square of the velocity, higher speeds cause a material increase in the power of the auxiliaries.

To obtain a high vacuum in the turbine exhaust it is essential that the frictional resistance of the steam across the tubes should be reduced to the minimum possible. For this reason the path of the steam must be direct into the condenser and the steam must spread itself over a large initial surface of tubes. Further, the bank of tubes should be as shallow as possible.

For these reasons, the so-called boat-shaped condenser (Fig. 1) has been developed by some makers. While this is a type possessing advantages, it is unsatisfactory in that it requires internal stays, which interfere with the flow of the steam, and is, moreover, expensive to construct. For these reasons, the English Electric Company have kept to the circular condenser, retaining the advantages without the disadvantages of the other type. This design was developed many years ago, and has given highly satisfactory results in practice. From Fig. 2 it is seen that the steam enters and distributes itself over a very large tube surface, extending from tube plate to tube plate, thus avoiding all dead pockets where condensation is not effective. At the same time the bank of tubes through which the steam has to pass does not exceed half the diameter of the condenser. Such a condenser is exceedingly simple in design—there is an entire absence of internal stays, there being nothing to obstruct the even and direct flow of the steam on to the tubes. The cylindrical shape permits of a plain casting without ribs, a frequent source of minute spongy places permitting air leaks.

When the steam enters the condenser it is relatively air free, that is to say, the volume of air entering the condenser is exceedingly small compared with the volume of the steam. As the steam is condensed the relative air volume increases until at the bottom of the condenser it reaches an appreciable amount. Experiments have been made which show that with a small quantity of stagnant air round the tubes, the rate of heat transmission is very materially reduced. This condition does not, however, occur in practice, because the air is not stagnant in a properly designed condenser, hence with a reasonably large air pump it can be said that for the greater portion of the tube surface there is no risk of reduction in heat transmission from this cause. It is very necessary to see that the air is withdrawn from the condenser in such a manner that it is swept straight across the tubes, and that no air pockets are formed. A suitable method is shown in Fig. 3, where the air branch is taken from the side of the condenser and communicates with the space inside a plate that extends the whole length of the body. No direct method of measuring the air entering a condenser exists, makers having arrived at suitable allowances by experience. Generally, 3 to 6 lbs. of air per 10,000 lbs. of steam is allowed, the higher figure for 3,000 K.W. sets and the smaller figure for 20,000 K.W. sets. The method of basing the air allowance on the quantity of the steam is very unsatisfactory, because only a very small amount of the air to be dealt with comes over with the steam itself, the bulk of it

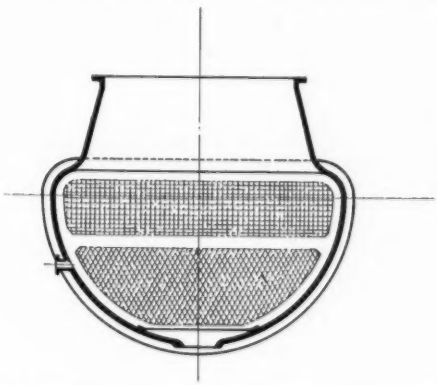

FIG. 1.—SECTION OF "BOAT-SHAPED" CONDENSER.

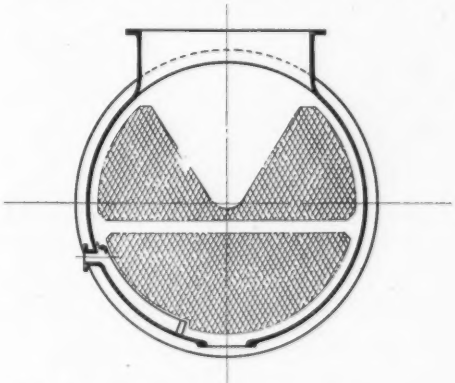

FIG. 2.—SECTION OF ENGLISH ELECTRIC CONDENSER.

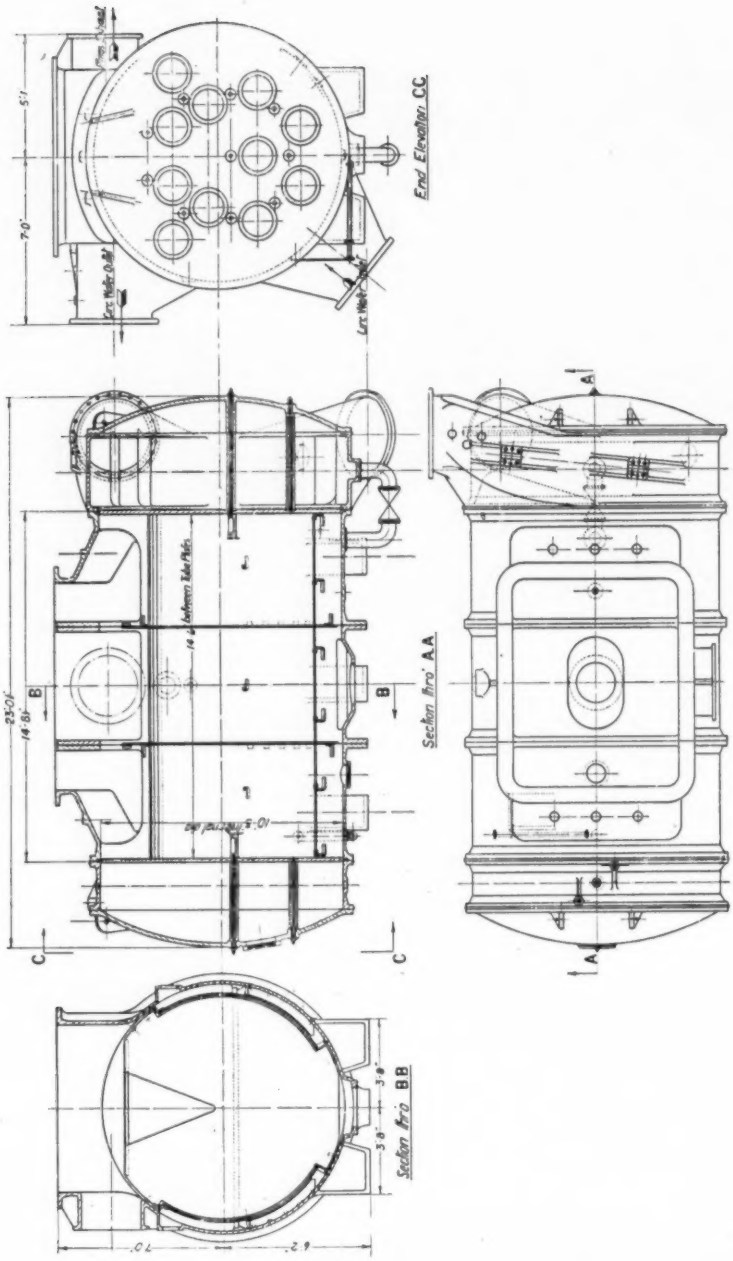
End Elevation CC
Section thro' AA
Plan
Section thro' BB
23'-0"
14'-8"
7'-0"
5'-1"
3'-0"
2'-9"
14 dia Inconel Tube Plate
End plate 5'-01

FIG. 3.

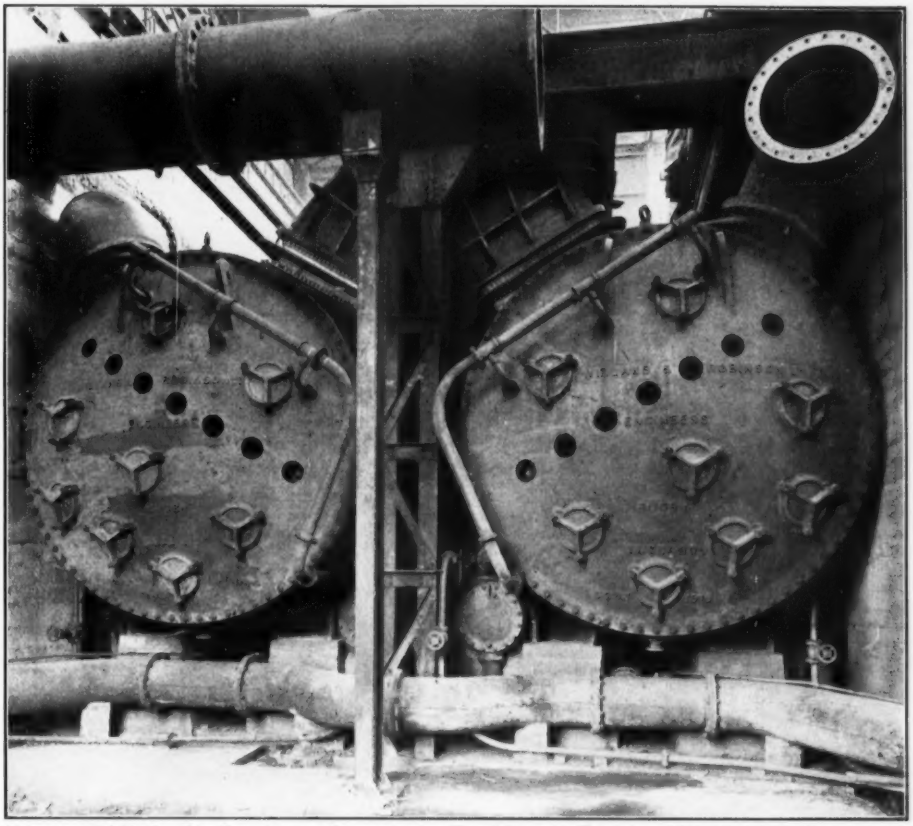

FIG. 4.—50,000 SQ. FT. CONDENSER SUPPLIED BY THE ENGLISH ELECTRIC COMPANY FOR ROTHERHAM.

entering the turbine glands and the joints in the exhaust piece and condenser, a small amount possibly entering through the castings, due to minute porous places undetected under water pressure tests. If a condenser is reasonably tight and the turbine glands in proper order, the actual air entering the condenser probably does not exceed half the amount allowed for. It is, however, advisable to have ample air capacity in the air-extraction plant. An excess of air can usually be detected by noting the difference between the temperature of the condensate in the bottom of the condenser and the actual vacuum. If, for instance, with a 28½″ vacuum the condensate has a temperature of 86°F., then the air pressure in the condenser, presupposing that the condensate is properly drained from the condenser and the bottom tubes are not drowned, is—

Vacuum at 28½″	..	=	1·500 ins. abs.
Vapour pressure at 86°F.		=	1·260 „ „
Air pressure		=	0·240 „ „

If the condensate temperature fell to, say, 80°F., the air pressure increases to—

Vacuum at 28½″		=	1·500 ins. abs.
Vapour pressure at 80°F.		=	1·039 „ „
Air pressure		=	0·461 „ „

or nearly double the pressure. If the air pump volumetric efficiency was the same at both pressures, then nearly twice the weight of air would be leaking into the condenser in the latter case as compared with the former. Actually, the air pump volumetric efficiency is not constant at air pressures below 1·00″ mercury. The reciprocating pump falling off rapidly below this

point, although it is fairly constant above it.

When testing air pumps by blanking off the air suction pipe and inserting nozzles, proper correction must be made for the different conditions under which the pump operates; this correction, of course, depends upon the type of pump used. As an example, consider an air extraction plant of the steam jet type. As this operates by steam and has no cooling medium such as sealing water, it is essential to fit a number of condenser tubes inside the air baffle plate in the condenser, referred to above. These tubes should only be in the lower pass of the water, in order that the coldest water only passes through them; by this means the saturated air is cooled to a temperature a few degrees above that of the cooling water temperature. If this temperature is 68°F., the vacuum 28½", and the condensate 86°F., the saturated air might be cooled to, say, 72°F. The air pressure at the ejector inlet is then—

Vacuum at 28½" ..	=	1·500 ins. abs.
Vapour pressure at 72°F.	=	1·797 ins. abs.
Air pressure ..	=	0·703 ,, ,,

At 72°F. dry air has a volume of 13·40 cubic ft. per lb. at atmospheric pressure. If the plant has to deal with 50 lbs. of air per hour, the volumetric capacity of the ejector is—

$$\frac{50 \times 13{\cdot}40 \times 30}{0{\cdot}703} = 28{,}600 \text{ cubic ft. per hour.}$$

If the ejector is tested by means of a nozzle drawing dry air at, say, 62°F. into the ejector, the air pressure at 28½" will be 1·500 ins. abs., since the air is dry. The volume of air at 62°F. is 13·15 cubic ft. per lb., and the weight of air actually dealt with would be—

$$\frac{28{,}600 \times 1{\cdot}5}{13{\cdot}15 \times 30} = 108 \text{ lbs. per hour,}$$

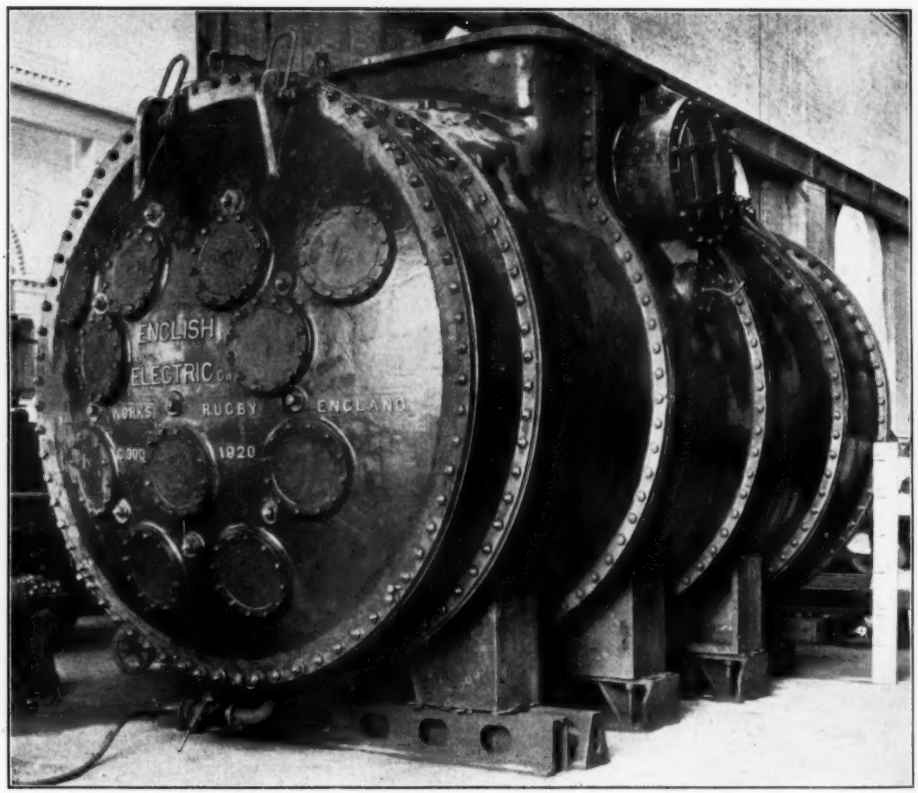

FIG. 5.—20,000 SQ. FT. CONDENSER SUPPLIED BY THE ENGLISH ELECTRIC COMPANY TO THE SHEFFIELD CORPORATION.

FIG. 6.—TRANSPORTING ENGLISH ELECTRIC COMPANY CONDENSER IN SECTIONS.

whereas under actual working conditions it only deals with less than half this amount. It is evident from these figures that it is imperative to get the air out of the condenser at as low a temperature as possible, just as it is necessary to withdraw the condensate as hot as can be arranged. For the reason that it is uneconomical to use the condensate for sealing the air pump, the air plant is kept separate from the condensate pump.

With air extractors of the water jet type or with reciprocating pumps using cold sealing water, such as the condenser cooling water, the air nozzle test gives the same capacity as when the plant is coupled to the condenser, since the air is cooled by the sealing or injection water which is at the same temperature in both cases.

A most important factor in the design of surface plants is the fouling of the tubes. This is confined almost wholly to the water side of the wall. It is, of course, quite impossible to deal with this by any formula or rule. The fact should be recognised by the purchaser and a very ample surface agreed upon. The fouling may be caused by soft mud or factory refuse, such as wool combings, tannery tailings, etc., or vegetable matter, such as leaves, grass, etc. If not allowed to cake and dry, this can generally be cleaned out without a great deal of difficulty, but it is not sufficient merely to scrape out the mud; the tube surface should be properly cleaned.

Certain waters leave a hard scale that is exceedingly difficult to remove, even when boiling out with acid is resorted to. This frequently happens with cooling tower plants, where the water is hard. Since the cooling tower is essentially an evaporator, the circulating water becomes concentrated and the accumulation of salts reach a really dangerous figure. In such cases softening plants should be installed, to deal not only with the make-up water, but, if necessary, with the pond water, by continuously passing a small amount through them.

It is almost impossible to get the tube surface back to its original condition to give the water proper metallic contact with the wall of metal; consequently, allowance must be made, not only with the frequency in which the plant can be shut down for cleaning, but for the fact that the rate of heat transmission falls with the thinnest of dirt films inside the tube.

By increasing the surface, allowance can be made not only for the reduction in heat transmission, thus maintaining an economical vacuum, but for increasing the period between cleaning. Obviously, the station load has a bearing on this question, and experience alone can decide how much extra surface it is advisable to pay for. Various methods have been adopted for facilitating the cleaning; such, for instance, as dividing the surface in large plants between two shells, enabling one to be cut out for cleaning while the other carries the load at a reduced vacuum. This arrangement is particularly convenient for double exhaust turbines, and even for large sets, when it is generally slightly cheaper to build two condensers rather than one large one. An example of this is the English Electric Company's 50,000 sq. ft. condenser for Rotherham (illustrated in Fig. 4), where the exhaust from a 30,000 K.W. unit is divided into two condensers by a breeches pipe. Each condenser has a surface of 25,000 sq. ft., and is 11′ 6″ inside diameter. For small condensers, where it would be expensive to fit two, the single condenser can be divided to permit of half being cleaned out at a time. To facilitate the cleaning, a steam ejector is sometimes fitted to the water-box with return pipes in such a way that, when the water valves are closed, the water can be heated and circulated through the tubes, a suitable re-agent, such as caustic soda or hydrochloric acid, being added. The length of time to be allowed for boiling depends upon the actual circulation and on the hardness of the scale. It may be as low as six hours, but if the conditions are bad, 24 hours may be necessary to sufficiently soften the scale to enable it to be cleaned out.

It is obvious that frequent cleanings with a weak solution are very much better than cleaning at long intervals, when a stronger solution is necessary. By this means the tubes are kept clearer and the condenser will maintain a better vacuum; also the risk of damage to the condenser tube packing is much less with a weak solution. Experiments with hydrochloric acid on standard tube grummets soaked in boiled oil indicate no effect on the grummets

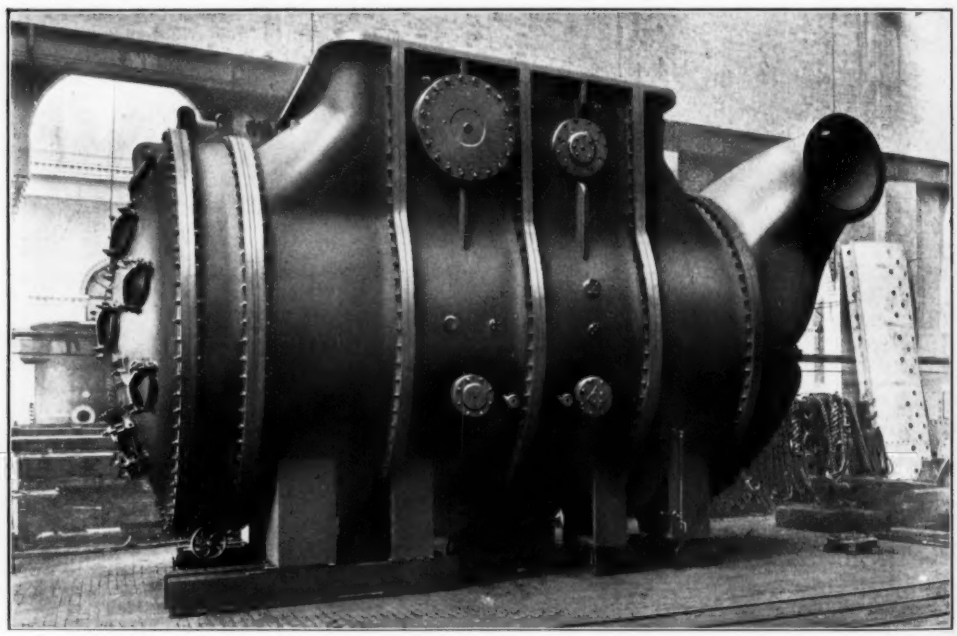

FIG. 7.—SURFACE CONDENSER DESIGNED AND CONSTRUCTED BY THE ENGLISH ELECTRIC COMPANY FOR USE WITH AN ENGLISH ELECTRIC COMPANY 15,000 K.W. TURBINE IN THE DALMARNOCK POWER HOUSE OF THE GLASGOW CORPORATION ELECTRICITY DEPARTMENT.

with a 20% solution of pure acid or a 50% solution of commercial acid when cold. A 20% solution of commercial acid heated to 140°F. also had no effect, but when heated to 180°F. a slight weakening of the fibre of the treated grummets was noticeable and untreated ones rotted. The treated grummets rotted when boiled in the same solution for 10 minutes. These experiments clearly limit a 20% solution of commercial acid to 140°F., and even this is not advisable if the cleaning has to be done frequently.

The transportation factor enters into the design of a condenser as in practically all present-day problems. The limitation of the British loading gauge is a serious item and requires careful consideration. Generally speaking, condensers up to 8′ 0″ internal diameter can be tubed at the maker's works, and so delivered to site. Above 9′ 0″ diameter it is nearly always impossible to deliver the shell in one piece. Up to 11′ 6″ the shell can be made in rings and transported as shown in Fig. 6, which illustrates the four rings comprising one body, without the water-boxes, for the Rotherham condenser referred to above. Above 11′ 6″ it is practically impossible to adopt the ring construction, and the body and water-boxes require dividing into segments. This is objectionable, not only on account of the cost, but for structural reasons. Since about 25,000 sq. ft. is the greatest surface that can be accommodated in the ring type body, the segmental type must be used for all large units, 20,000 K.W. and upwards.

The calculations required to run out the dimensions of a surface condenser are few and simple, but from what has been said above, it is clear that considerable judgment, based on practical experience, is required to determine the constants that are used. These constants are ascertained from very many tests on new and old condensers, and are the accumulation of some 17 years' experience. Although there are only two main variables in fixing the size of a condenser, namely, the weight of steam to be condensed and the temperature of the cooling water, a large number of minor variables and conditions must be taken into account.

The principal calculations are as follows :—

t_1 = temperature of cooling water inlet.
t_2 = temperature of cooling water outlet.
t_s = temperature of steam in the condenser.
$\theta_1 = t_s - t_1$
$\theta_2 = t_s - t_2$

The temperature differences are first determined and the mean temperature difference found thus :—

$$\theta_m = \frac{\theta_1 - \theta_2}{\log_e \frac{\theta_1}{\theta_2}}$$

The water velocity is assumed and the rate of heat transmission—

$$K = C\sqrt{v}$$

where C = a constant varying from, say, 150 to 220, and v = velocity of water through the tubes in ft. per second. Further :—

W = weight of steam, lbs. per hour.
S = total surface in sq. ft.
$w = \frac{W}{S}$
h = heat rejected to condenser in B.Th.U. per lb. of steam.

Since K is the rate of heat transmission in B.Th.U. per sq. foot per °F. mean temperature difference per hour—

$$w = \frac{K.\theta_m}{h}$$

and $$S = \frac{W.h}{K\,\theta_m}$$

If Q = Cooling water in gallons per min.
then $600\,Q\,(t_2 - t_1) = W.h$
and $$Q = \frac{W.h}{600\,(t_2 - t_1)}$$

l = length of tubes between the tube plates.
m = number of water passes.
L = $m.l$ = length of tube unit.
n = number of tubes per pass.
N = $m.n.$ = total number of tubes in condenser.

With ¾″ external diameter tubes, 18 I.S.W.G. thick, 5·094 lin. feet equal one square foot of surface; also the cross sectional area of 429 tubes equals one square foot.

Then $$n = \frac{1{\cdot}15\,Q}{v}$$

and $$L = \frac{5{\cdot}094.S}{n}$$

The number of ¾″ diameter tubes per square foot of tube plate area varies from 70 to 100, according to the arrangement of tubes on the plate, the diameter of the condenser, and the number of water passes.

Generally speaking, small condensers require four water passes; medium ones three, and large ones two passes, arranged to give a reasonable proportion of length to diameter.

An example of a modern medium size condenser is illustrated in Figs. 3 & 5. This condenser

has a surface of 20,000 sq. ft., and is for dealing with the exhaust steam from a 10,000 K.W. steam turbine for the Sheffield Corporation, to the specification of Mr. S. E. Fedden, M.Inst.C.E., the whole of the plant for this set being manufactured by The English Electric Company. As shown, the body is made in three rings, the flanges of the two middle joints being carried across the exhaust opening. The cooling water makes two

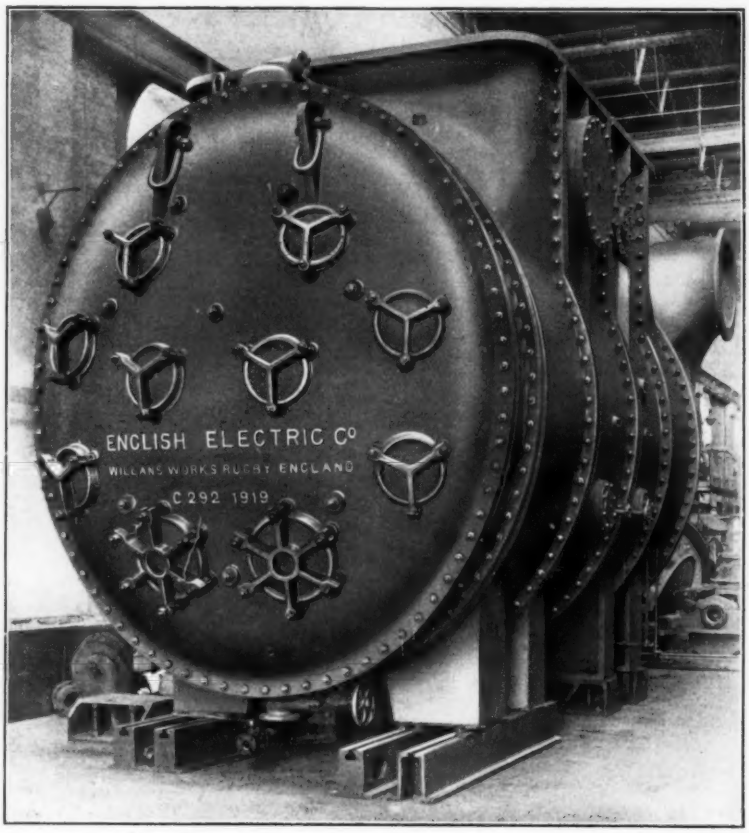

FIG. 8.—ANOTHER VIEW OF THE ENGLISH ELECTRIC COMPANY DALMARNOCK CONDENSER.

passes through the tubes, the inlet being at the bottom and the outlet at the top. In accordance with usual practice, the water branches are attached to the water-box and independent of the cover, which permits of the latter being removed and the tubes cleaned or replaced without breaking the pipe joints. The return water-box consists of a ring with a cover similar to the inlet box door. The tubes, 7,030 in number, are of Admiralty mixture (Cu. 70; Zn. 29; Sn. 1) $\frac{3}{4}$" external diameter by 18 I.S.W.G. thick. They are supported at the ends by rolled brass tube plates in stuffing boxes packed with hemp tape grummets soaked in boiled oil, tightened up by brass ferrules having an internal lip at the outer end to permit of the expansion of the tubes without displacement. The ferrules have well rounded entrances to permit the easy entering and discharging of the water. The intermediate support plates of rolled brass assist in carrying the weight of the tubes and water. The steam enters a large rectangular opening 8′ 8″ × 7′0″, well arranged over the top tubes; this, together with the large V-shaped lane, referred to above, gives a perfect distribution of the steam over a large number of tubes.

The tube plates are supported by a recess in the body flange and are screwed to a heavy cast iron girder across the condenser, and are also stayed to the covers by a number of bolts passing through distance pieces. Hydraulic joints are made on both sides of the cover where the stays pass through.

Each cover is fitted with a large number of inspection doors, so arranged that the doors of one cover stagger those of the other. By this means it is possible to see through nearly all the tubes by holding a lamp at the opposite end. The condenser is bolted direct to the turbine

exhaust flange and is supported on six groups of springs, so designed that they can be removed without dismantling the condenser.

The air is withdrawn from both sides of the condenser through the bottoms of the two baffle plates which follow the curve of the body and extend the whole length between the tube plates. The air ejectors, which are of the water jet type, are connected to the branches at the top of the baffle plates. The condensate pump is connected to the sunk facing on the bottom of the middle section of the body.

An interesting example of a large condenser is shown in Figs. 7, 8 and 9. This is for a 15,000 K.W. English Electric set at the Dalmarnock Station of the Glasgow Corporation Electricity Department. The condenser has a surface of 26,000 sq. ft. and is built for a vacuum of 29·1 in. with 50°F. water. A novel feature is the inlet and outlet water-boxes; instead of following the usual practice, the builders obtained the consent of Mr. W. W. Lackie, C.B.E., M.Inst.C.E., then Engineer and Manager to the Department to approve of the English Electric Company's arrangement and make them as shown. This arrangement permits of easy stream line flow of the water from the pipe line (40″ diameter) into the tubes, and from the tubes to the return pipe. By this means the frictional resistance required to get the water into the condenser and out again is reduced, making a saving in the power required by the circulating pump motor. Owing to the large size, these water-boxes are large enough for men to work in them when retubing or cleaning, the large door at the opposite end being removed.

Owing to the Scotch railway loading gauge being less than the English, it was not possible to keep to the circular section, and solely for reasons of transport, the condenser is made slightly elliptical. Each ring section was loaded on its side on special trucks, thus enabling the railway companies to handle it. In other respects this condenser is generally on the lines of the Sheffield one already described.

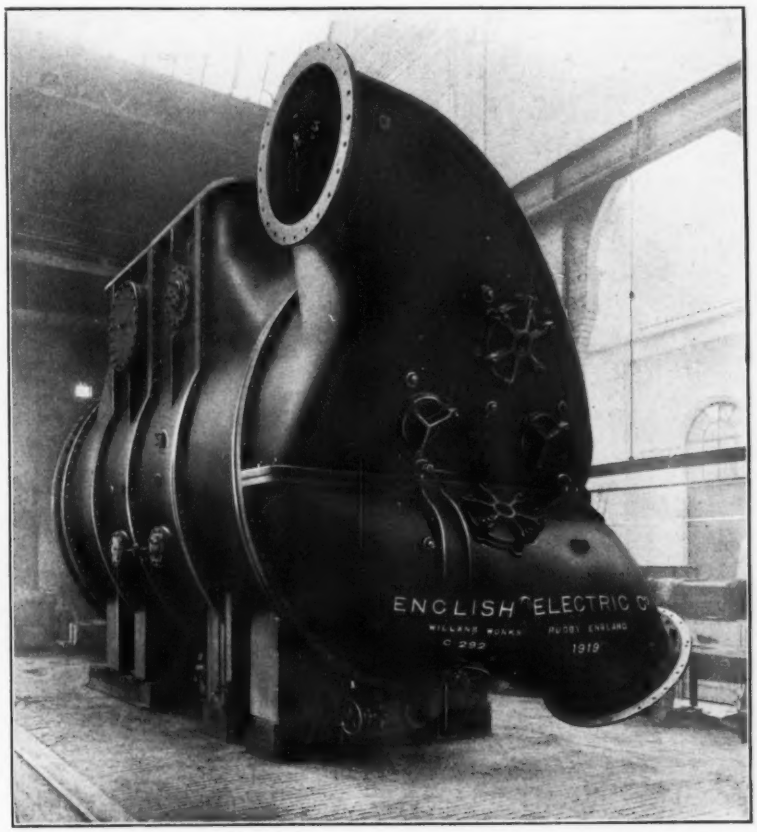

FIG. 9.—END VIEW OF THE ENGLISH ELECTRIC COMPANY DALMARNOCK CONDENSER, SHOWING INLET AND OUTLET WATER-BOXES.

Ball Bearings for Electric Motors

By P. Howden.

[*In the description of the English Electric Standard Industrial Electric Motor which appears in another part of the Journal, it is stated that ball and roller bearings are used throughout the whole range of these motors, and it will therefore be of interest to our readers to learn what the user of electric motors has to say on this subject. Our attention was recently drawn to an article which appeared in "Machinery" on March 17th last, by Mr. P. Howden, who, we understand, is Chief Electrician to one of the largest firms of machine tool makers in the country. It is most gratifying to find that although he, like so many others, was originally prejudiced against the use of ball bearings in electric motors, experience in the use of motors fitted with this device has led him to reverse his opinion to the extent shown in the following article. We take this opportunity of making our acknowledgments to the Editor of "Machinery" for permission to reprint the article.*]

There is apparently some divergence of opinion amongst engineers in general, and electrical engineers in particular, as to the advisability of fitting ball and roller bearings to electric motors. I have met engineers who have condemned them most wholeheartedly.

At the time when ball bearings were first introduced on electric motors, a great deal of trouble was experienced due to improper fitting and to using bearings not suited to the conditions. I have seen a 30-H.P. D.C. motor shaft worn down $\frac{1}{8}$-inch, thereby allowing the armature to foul the pole pieces, due to the inner ball race not being a tight fit on the armature shaft.

Due to early experience of failures of ball bearings, I was, along with many others, prejudiced against the use of ball bearings on motors. However, a number of motors fitted with this class of bearing were bought by my employers and installed on various machine tools, and the freedom from breakdown experienced with these motors compelled me to change my opinion, and I asked my firm to buy ball and roller bearing motors whenever any were required. Imagine my surprise when I was informed that only one large motor manufacturer could be found at that time (1913) who adopted this class of bearing as a standard, that two of the largest manufacturers definitely refused to fit them, and that several others would only fit them at an exorbitant price. Since then some makers have started to use ball bearings and, I believe, with good results.

My firm have installed a fair number of ball and roller bearing motors by different makers, amongst these, ten 50-H.P. squirrel-cage induction motors, manufactured by the English Electric Company, Bradford. These were installed in a shell factory. These ten motors ran at a speed of 710 R.P.M., and were fitted with pulleys, 12 inches in diameter by 12-inch face. The belts had to be kept tight due to the motors having to stand overloads of 50 per cent. to 60 per cent. for periods of 15 minutes in every hour's run. After running 115 hours a week for $2\frac{1}{2}$ years, under these conditions, the bearings were examined and found to be in a condition equal to that when installed. A 60-H.P. slip-ring motor driving a pump, through gearing, gave equally good results over the same period. These motors were fitted with a roller bearing at the pulley end, and ball bearing and double-thrust washer at the other end. The only repairs necessary during the $2\frac{1}{2}$ years was the renewal of one double-thrust washer which was damaged by a fitter who tried driving a pulley on with a 28-lb. hammer.

Yearly Inspection of Bearings.

During the same period we had 17 failures on ring oiled sleeve bearings, five of which resulted in the burning out of the stator coils, due to white metal bearings "running" sufficiently for the rotor to rub the stator core.

In order to reduce the number of sleeve bearing failures to a minimum, a weekly inspection of these bearings has had to be instituted. The ball and roller bearings are only inspected once a year, when the motors are dismantled, cleaned, the windings varnished, and the bearings thoroughly cleaned and filled with new grease.

The advantages we have experienced since adopting ball and roller bearings are: (1) substantial reduction of bearing failures; (2) 60 per cent. reduction in cost of attention and maintenance; (3) the possibility of fitting tight

belts, if required, without damaging bearings; (4) correct air gap maintained, with long life of bearings; (5) marked reduction in the number of electrical failures, due chiefly to the fact that no oil accumulates on the windings. With the ring oiled sleeve bearings, oil very often creeps along the shaft or runs into the machine, due to overfilling the oil wells. There is always the temptation to over-oil the bearings.

In order to secure the best results the writer suggests that the following points should be strictly adhered to:—

Roller bearings should be fitted at the pulley end of all motors above 7½ H.P. Effective means should be provided to take up end thrust on the armature or rotor. All bearings should be carefully fitted to the makers' instructions by competent men. The bearings should be suitable and heavy enough for the work they are called upon to perform.

Users should dismantle, thoroughly clean, and refill the bearings with new grease after 5,000 hours' running, under average conditions, and more often under adverse conditions. Provided the above points are adhered to motors fitted with ball and roller bearings will, in my opinion, prove to be far more reliable than if fitted with oiled ring sleeve bearings.

SCHEDULE OF MANUFACTURES OF THE ENGLISH ELECTRIC COMPANY, LIMITED.

Electrical Generating Plant of all capacities.

Steam Turbines and Condensers.

Water Turbines and Impulse Wheels.

Internal Combustion Engines.

Rotary Converters.

Static Transformers.

Switchgear and Controlling Apparatus of all kinds.

Electric Locomotives.

Electrical Equipment and Rolling Stock for Railways and Tramways.

Electric Plant for Rolling Mills, Iron, Steel, Copper Works, etc.

Electric Winding Equipments for Mines.

Standard Industrial Motors.

Incandescent Lamps, Domestic Heating Apparatus and Electrical Accessories.

Electric Locomotives for Industrial Purposes

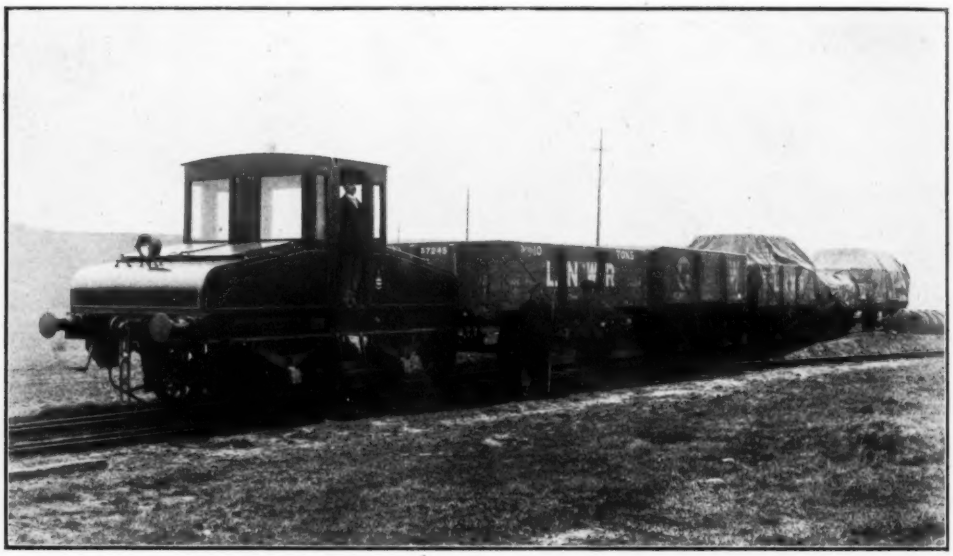

FIG. 1.

The question of the substitution of the electric locomotive for the steam locomotive in industrial work is now receiving the attention the subject deserves. It has long been recognized that the small steam locomotive, for industrial purposes or in shunting yards, is wasteful and inefficient, but in the majority of cases this has been regarded as a necessary evil. The inertia of an established institution is notoriously great and, generally speaking, the introduction of electric traction previously to 1914 was confined to tramways and passenger-carrying railway stock, while the electric locomotive for industrial work had only obtained slight recognition. It is impossible to estimate what might have happened between 1914 and 1920 had normal conditions existed, but there is no doubt that the economic position has greatly changed during that period, and the question must now be studied from a different point of view.

The cost of production has greatly increased, and two of the main factors which have caused this are dear coal and high wages. Because of the high cost of coal and labour, any saving which can be effected in the use of either or both must reflect very markedly on the cost of production. When labour and coal were cheap, a certain amount of waste was not relatively important, but this is not the case to-day.

In most works one source of waste is in the handling of material with steam locomotives. Consider the proportion of time spent in doing useful work to the total time during which the steam locomotive is burning fuel and using water. Before going into service, steam has to be raised, necessitating the attendance of a fireman; then bunkers have to be filled and water has to be taken on board. During service, when not usefully occupied, the consumption of fuel and water still goes on, and in the majority

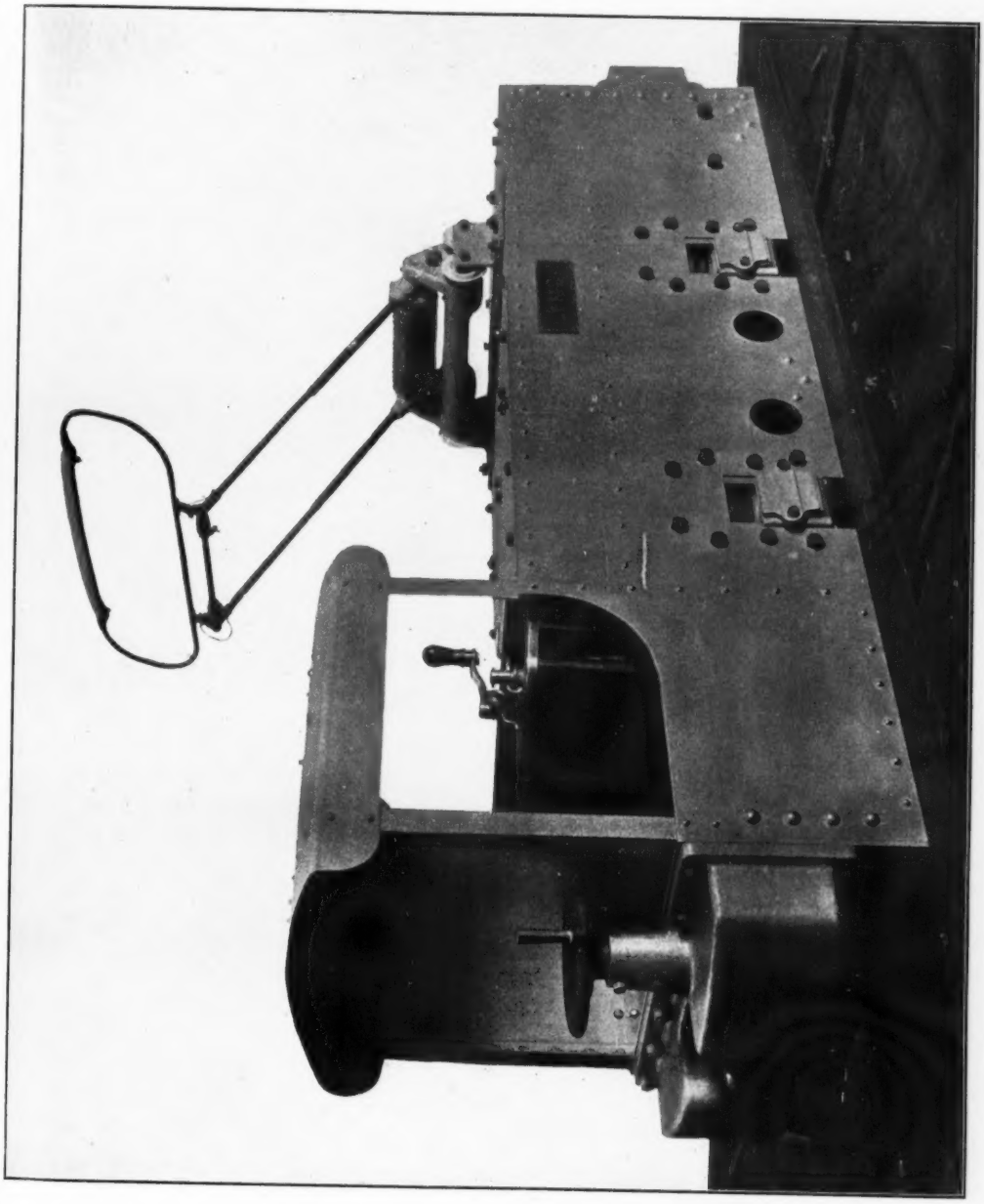

FIG. 2.

of works these standby losses must necessarily be considerable. After service the fires have to be drawn and the ashes cleared away.

In addition to this daily waste, the steam locomotive must be withdrawn from service at intervals for boiler washing, repairs to fire-box, repairs to glands and numerous other small fittings. At longer periods the steam locomotive must have its boiler thoroughly cleaned and re-tubed. During the time these repairs and renewals are being effected, besides the labour and inconvenience entailed, the locomotive represents capital laid idle.

As an alternative, it is claimed that an electric locomotive eliminates a great deal of this waste. It is ready for use when required. There are no standby losses. At the end of the day it can be put in the shed and left. The drive is through rotational machinery, and, consequently, the torque is even, which means that the driving parts do not have to withstand the impulsive forces to which the steam locomotive is subjected. Repairs are infrequent and quickly effected.

A steam locomotive must be engined for the heaviest load to be hauled, but this is not the case with an electric locomotive. The latter can be motored for the normal load, as it is capable of sustaining heavy overloads for short periods.

In addition to the above points, the electric locomotive scores because it is clean, needs the minimum amount of labour for driving, and is less likely to cause fires. There is always danger of fire with a steam locomotive, due to sparks and red-hot cinders, and it is a fact that insurance companies are willing to accept smaller premiums when electric locomotives are substituted for steam locomotives.

The works in which locomotives are used may be divided broadly into two kinds:—

(1) Those which require intermittent service.
(2) Those which require continuous service.

In the first class there are power stations, gas works, and small factories where the large railways deliver and collect material three or four times a day.

In the second class there are colliery yards, steel works, and large works generally.

In addition to these, there are others where special conditions exist, such as wood yards, docks, paper mills, etc., where cleanliness and the prevention of fire is of great importance.

For the first class a battery locomotive may be used, while, generally speaking, a trolley locomotive is recommended for the second class. There may, however, be objections to the installation of overhead wires, and then the battery locomotive must be used.

Sometimes a combination of the two is advisable, as in the case of the ordinary steel works. A steel works usually has a fairly level track alongside the furnaces and a heavy grade up to a slag tip; near the furnaces, overhead wires are objectionable, but up the grade they can be installed without inconvenience. On the level, therefore, it is necessary to use a battery, but up the grade, where a heavy demand would be made on the battery, the locomotive runs on the trolley wire. The use of the trolley wire up the grade enables the battery to be kept within reasonable dimensions, or, alternatively, it does not need to be charged at such frequent intervals.

As a guide to the relative costs of steam and electric locomotives on a basis of work done, the following figures have been compiled, and although it is not claimed that they will apply in all cases, there is no doubt that they are representative and do not unduly favour the electric locomotive. The figures for repairs and maintenance, depreciation and interest on capital include all charges attendant on each system. For steam locomotives account has been taken of coaling, watering and repair plant, and for electric locomotives, overhead line, battery charging, converting and repair plant have been allowed for.

In the following table 100 has been taken as a basis figure for each item:—

	Steam.	Trolley.	Battery.
Repairs and maintenance	100	33	50
Power	100	33	40
Lubrication and miscellaneous	100	33	33
Wages	100	50	50
Depreciation	100	60	90
Interest on capital ..	80	100	100

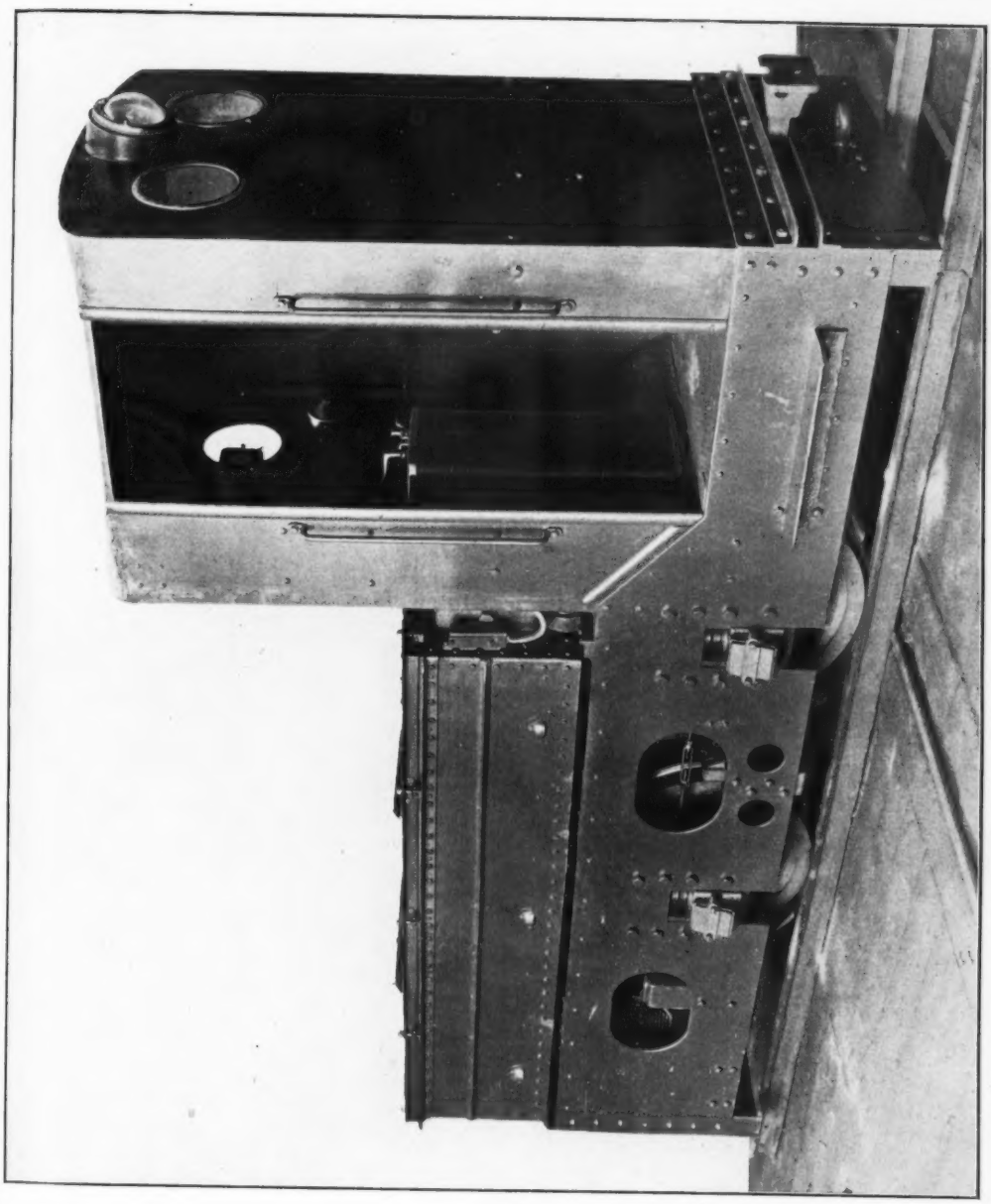

FIG. 3.

The overall operating costs of the three systems are in the following proportion :—

Steam 100, Electric Battery 60, Electric Trolley 50.

The only item in which steam traction compares favourably with electric traction is in capital cost, but the total annual saving in operating costs is such that even with a small system this extra cost is wiped out in less than two years.

The figures given above are for small systems where only one locomotive is used. On larger systems, however, greater economy would be effected by the use of electric traction, as a number of steam locomotives can be displaced by a smaller number of electric locomotives. The proportion varies according to the nature of the service. For intermittent service two electric locomotives would do the same amount of work as three or four steam locomotives. Where the service is continuous, one electric locomotive of the trolley type would be required in place of each two steam locomotives, while, if battery locomotives were employed, one locomotive and one spare battery would be necessary.

The larger the system the greater becomes the ratio of steam to electric locomotives required for the work, and this difference offsets the higher cost of the electric locomotive.

In further consideration of the capital cost, it is important to remember that where, with steam work, a spare locomotive would be required, an electric system requires only a spare armature. Also, electricity is so generally used for power purposes, that the majority of works would only incur a small additional cost by installing the necessary plant for supplying current to the line or for charging batteries. In regard to this auxiliary plant, it is well to point out that an increased number of locomotives requires only a small increase, if any, in the overhead and battery charging plant provided. The overall capital cost per electric locomotive is thus reduced where several locomotives are employed, and the total capital cost is little different from that of the requisite number of steam locomotives with their water, coal and repair plant.

Realising the trend of progress, the English Electric Company, as a result of a searching enquiry into present-day conditions, has developed a line of locomotives suitable for a wide range of requirements. A number of difficulties had to be contended with, due to the fact that conditions are very variable. Track gauges vary from 18 in. to 5 ft. 6 in.; the voltages of available supplies differ; stock to be hauled and numerous other details are met with in infinite variety; all of these have influence on the design of the locomotive. Nevertheless, it is believed that the types developed will meet almost all industrial requirements. These locomotives range in weight from about 4 tons to 22 tons on two axles, heavier and larger locomotives being classed under a different category.

Examples and photographs of these standard locomotives recently constructed are given below.

Type 1A locomotive, illustrated in Fig. 2, is the smallest of the three types developed. It can be arranged to suit all gauges from 1 ft. 6 in. to 2 ft. 6 in., and has been specially designed for work in confined spaces. On the minimum gauge the overall width is 2 ft. 10 in., and the minimum height over the cab roof is 3 ft. 6 in. It is fitted with 16 in. wheels and has a 3 ft. wheel base, so that it can negotiate curves of 14 ft. radius. The frame is built up of steel plate, braced with stretcher plates and angle iron, to which the cast steel horn guides are attached. The weight of the frame is taken on the axle boxes by helical springs. The cab affords head protection to the driver and is open at the sides. The screw-down hand brake operates brake blocks on the inside of each wheel.

The electric equipment consists of two 11-H.P. motors, each driving on to its axle through worm gearing, and a series parallel controller with seven power notches and five rheostatic braking notches. The normal speed is five to six miles per hour, and the maximum tractive effort is

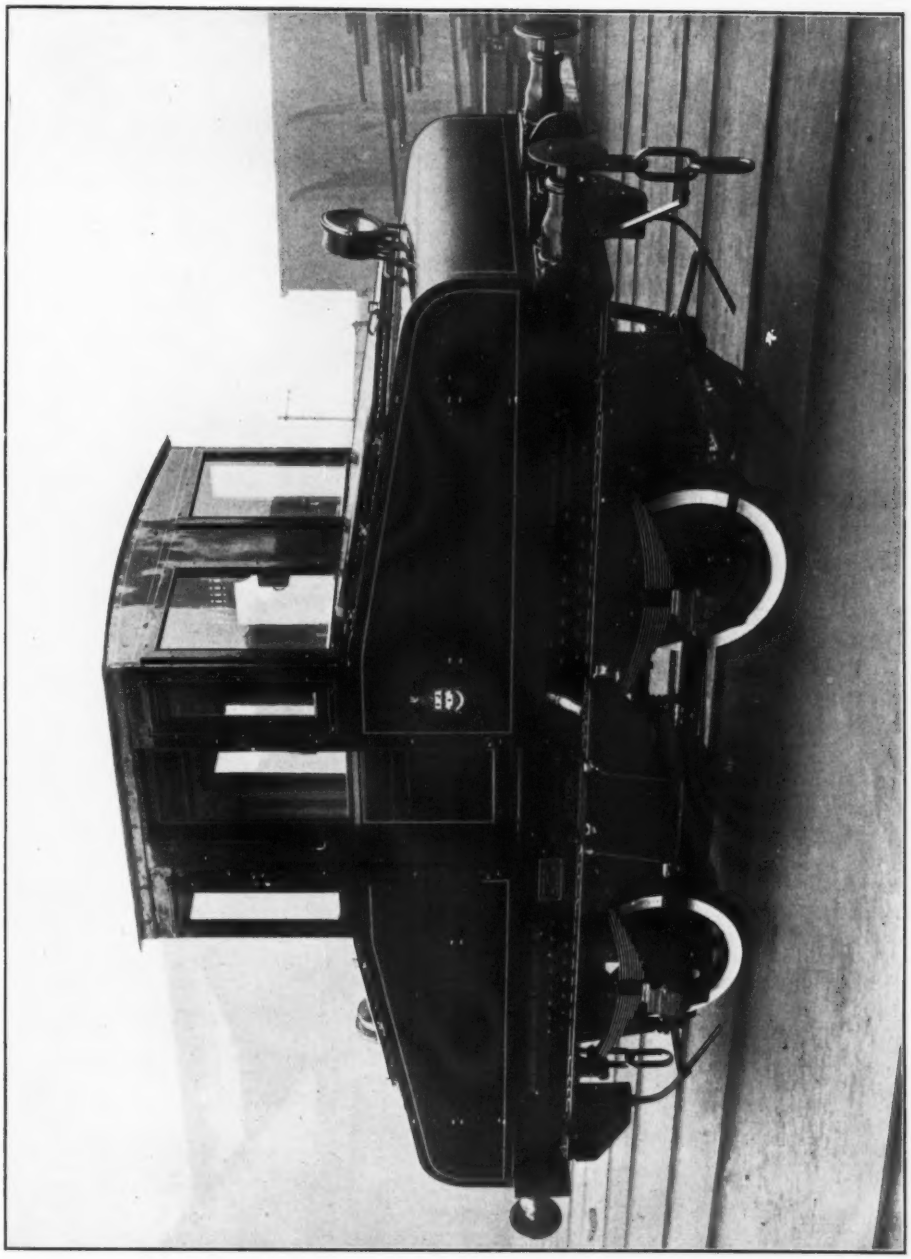

FIG. 4.

2,000 lbs. at the tread of the wheels. A circuit breaker and an ammeter are fitted inside the cab, whilst the resistances of standard grid pattern are carried inside the framing at the rear end of the locomotive. A voltmeter, ammeter, and ampere-hour meter are supplied with locomotives of the battery type.

The weight of the locomotive, complete with electrical equipment and battery or ballast, is 3½ tons.

When the locomotive is to operate from a battery, this is contained in a removable ventilated compartment, which is fitted with wheels so that it can be run off the top of the locomotive on to a charging table. It is a matter of a few moments only to disconnect the battery and replace it with a spare battery when the used ones need recharging.

Type 2 locomotive, illustrated in Fig. 3, is larger, but generally similar in construction to the 1A. It is arranged to work on gauges from 2 ft. to 3 ft. 6 in. With a wheel base of 3 ft. 11 in., it can negotiate curves of 20 ft. radius.

The wheels are 32 in. in diameter, so that it is possible to use standard traction type motors driving direct on to the axles through spur gearing. Two motors ranging from 12-H.P. to 35-H.P. each, according to gauge, voltage and speed required, are controlled by a standard series parallel controller. The maximum tractive effort at the tread of the wheels is 4,000 lbs., and the normal speed is from 6 to 10 miles per hour, according to requirements. The total weight of the locomotive is approximately 7 tons.

This locomotive can be equipped with a removable battery compartment, or with a standard bow trolley, mounted on a trolley standard to suit varying heights of wire.

Type No. 3 locomotive is adaptable for all gauges from one metre to 5 ft. 6 in. Two examples of this locomotive are illustrated in Figs. 1, 4 and 5.

This locomotive is of the central cab type, with sloping end covers, the ends being made to contain the batteries when these are required.

The general dimensions are :—

Length	.. ..	up to 21 ft. over the buffers.
Overall width	..	up to 8 ft. 9 in.
Minimum height over cab	.. ..	9 ft.
Wheel base	.. ..	6 ft. to 8 ft.

With a 6 ft. wheel base this type of locomotive can operate on a curve of 30 ft. radius. The frame is built up of rolled steel channel iron, strongly braced and riveted together, and it can be arranged for any type of buffer or combination of buffers.

The arrangement in the interior of the cab is comprehensive but simple. A series parallel controller of standard type having 4 series, 4 parallel and 7 braking notches, is fitted, so that the driver can operate the locomotive in either direction without changing his position. In the centre of the cab, and within easy reach of the driver, an operating wheel for the screw-down handbrake is fixed. Gong and sand-operating pedals are set in the floor close to the brake. An ammeter, a voltmeter and an ampere-hour meter are mounted on a vertical panel which is fixed between the two windows at one end of the cab. For trolley type locomotives an ammeter is the only instrument fitted. An automatic circuit-breaker is fixed inside the cab in an accessible position under the roof. The doors of the cab are of the sliding type, and one window in each side can be let down.

This type of locomotive is driven by two traction motors through spur gearing on to the axles. According to the nature of the work required and the voltage available, it can be fitted with motors varying from 15-H.P. to 90-H.P. each. The total weight of the locomotive can be varied from 11 to 22 tons. With the most powerful equipment it will give a normal tractive effort of 5,000 lbs., and for short periods 8,500 lbs. at the tread of the wheels. With the wide range of standard traction motors available, normal speeds of from 4 to 25 miles per hour can be arranged to suit individual requirements.

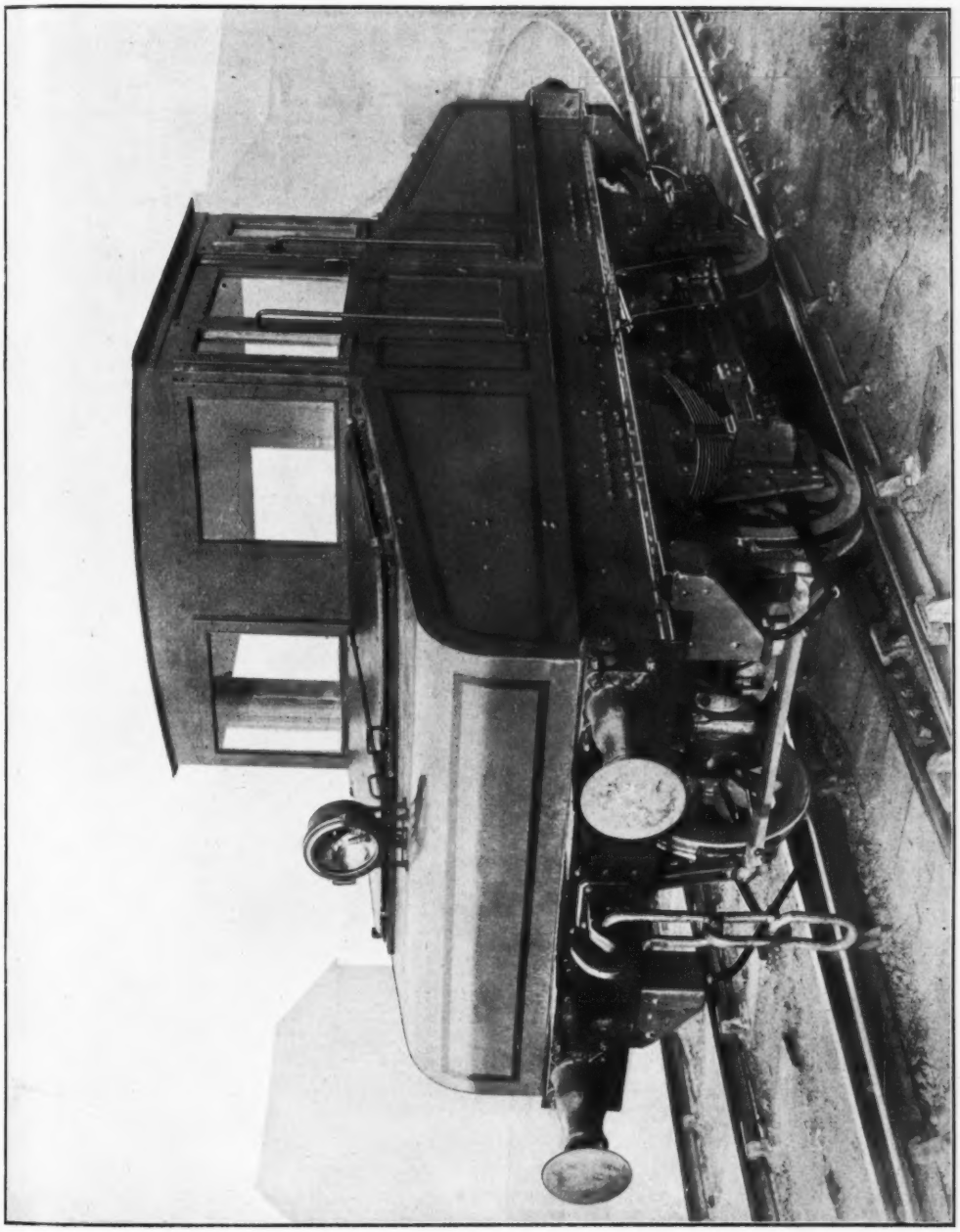

FIG. 5.

With locomotives of 18 tons or over, or where there are heavy grades, it is usual to supplement the hand and rheostatic brakes by an airbrake of standard manufacture, and the brake rigging is so arranged that this can be done without alteration to any standard fitting.

The arrangement of the battery compartments has received special attention. The compartments are weatherproof and fitted with ventilated covers, which, when open, allow for easy access to the cells for purposes of testing and repair. The interior of the compartments is painted with acid or alkali-resisting paint according to the type of battery installed, and when required by the battery maker, the compartment is fitted with an additional wood floor. The whole compartment is strongly braced and supported by an interior channel iron against which the battery is firmly wedged, to prevent displacement due to acceleration and shunting shocks.

The maximum capacity of battery which can be used with this type of locomotive naturally varies with the make of battery preferred and with the available charging voltage. In round figures, however, the capacity is 130-K.W. hours

The motors are standard series interpole traction motors exactly similar in type and construction to those manufactured in large numbers for tramways and light railways. They are manufactured, in common with all traction equipments, at the English Electric Company's Dick, Kerr Works, Preston.

The controller and under-car type resistances likewise present no new features from those proved by continuous use on existing systems.

The charging of the battery is carried out by connecting the supply to the battery by means of a socket and plug in the locomotive, and through a two-way charge and discharge switch which connects the battery through the circuit-breaker and an ampere-hour meter either to the supply or to the controller. The ampere-hour meter indicates the capacity of the battery both during charge and discharge, and is so arranged that on reading full charge an auxiliary tripping coil in the circuit-breaker is energized, thus opening the circuit between the battery and the supply.

The tripping coil is open-circuited by means of auxiliary contacts on the charge and discharge switch when the latter is set for operating the locomotive.

When batteries are fitted which consist of more than 160 cells in series, they are divided in half by an ironclad single-pole sectionalising switch to minimise the risk of shock when the cells are being examined and tested.

The main cabling is run in steel tubing.

For operation on a trolley system, part of the apparatus mentioned above is, obviously, not required, and the locomotive is then fitted with a standard current collector, fixed to a trolley plank firmly secured to the top of the cab. A lightning arrester of standard tramway type is also provided.

In the locomotives described above a wide range of requirements has been compassed with the minimum number of types. They are all constructed with a view to operating under severe conditions, having short wheel bases and being of robust construction to withstand the vibration and shocks due to indifferent track. In common with all standard electric stock, they are easy to operate, can be brought to rest exactly at the position required, and possess a high and constant acceleration up to a relatively high speed.

In conclusion, it is believed that the substitution of electric for steam traction for industrial purposes should materially contribute to reducing the present-day cost of production. The direct saving that would be effected is alone sufficient to justify the most careful study of the question by all users of industrial locomotives. But in addition there would be a very important economy effected in the national coal bill owing to the more efficient use of that product, and a still further saving on ton miles of coal hauled on the railways. It may be expected, therefore, that electric industrial haulage will result in increasingly efficient and economical production as this system comes to be generally adopted.

Two English Electric Products.

[It is our intention to describe in the Journal from time to time special products of the English Electric Company, and, in particular, machines and apparatus of new or revised design. In the following pages will be found a description of the English Electric Industrial Motor and of the Transformer for small and medium sizes.—EDITOR.]

The English Electric Industrial Motor.

Classes of Motor.—The English Electric Motor is made in two main classes :—

C.B. Motors—For Direct Current.

A.G. Motors (Squirrel-Cage Type) and A.G.S. Motors (Slipring Type)—for Two- or Three-Phase Current.

These motors embody the very latest developments in theory and practice, and are the result of the combined experience of the works now controlled by the English Electric Company. The underlying idea carried out in these machines is that every effort should be made to use the active material to the best possible advantage, while at the same time the machines should be so conservatively rated that the margin for overload is as great as in the older designs to which we are accustomed.

Before proceeding with the description of the machine, it may be helpful to review various considerations which influence the design from the purely technical point of view and also those connected with the element of production.

From the technical point of view, it is well known that the tendency in recent years has been to arrange for more and more efficient ventilation in every part of the machine. Instead of relying on the general fanning action of the armature or rotor, the ventilation has been planned out on a definite scheme, the paths for the ventilating air (see Figs. 8 and 9) being arranged to give each part its requisite amount of cooling. This feature has been given special attention in the design of both the D.C. and the A.C. motor, as will be seen from the following description, and by this means the weight of the whole machine has been considerably reduced without danger of over-heating or reduction of mechanical strength.

The machine is designed from start to finish for forced ventilation. A carefully designed fan of considerable size, as will be seen from the illustrations, is provided on the armature or rotor. This fan is not an afterthought or an accessory, but is a vital part of the design. It runs in a housing absolutely clear of the windings, and is firmly supported on bosses designed for the purpose. The design of the fan has been properly investigated, and the construction is such that the addition of the fan does not reduce the efficiency of the machine.

From the point of view of production the design must be as simple as possible. The whole of the castings must be of such a type that they can, as far as possible, be machine moulded, and the machining must be able to be carried out with the minimum number of settings, diameters, and so on. These points have received full consideration in the present design; for example, the same end-shields are used both for the D.C. and for the A.C. machines.

General Description.—The general design of the machines will be seen from the illustrations Figs. 1 to 6 and the sectional drawings Figs. 8 and 9, and is generally similar for both the D.C. and the A.C. machines. The protected-type machine (Fig. 1) has a perforated metal cover over the fan end of the armature, while the Enclosed-Ventilated machine (Figs. 4 and 5) has a similar perforated metal band over the commutator or slipring end also. Both these covers are easily erected, being merely slipped on and clipped in position. The advantage of this form of cover is that a machine can be easily converted from Protected type to Enclosed-Ventilated by the simple addition of a cover.

These motors can also be supplied as Pipe-Ventilated or Drip-Proof machines. The frame of these machines is the same as for the Protected type, but definite inlet and outlet openings are provided (all the other openings being closed), so that trunks can, if desired, be fitted to them.

The C.B. Motor has the inlet on the end shield, as shown in Fig. 3, but the Induction Motors have both inlet and outlet of evolute form as shown in Fig. 6. This inlet or outlet forms part of a cast ring which slips over the arms to which the end shields are bolted. The Pipe-Ventilated machine has the

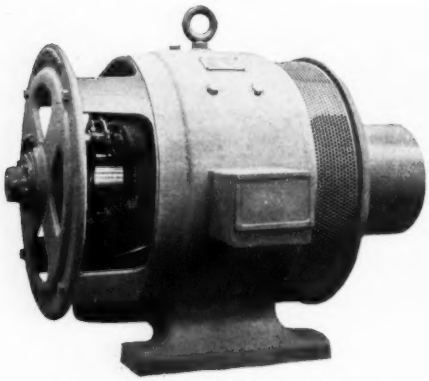

FIG. 1.—PROTECTED TYPE C.B. MOTOR.

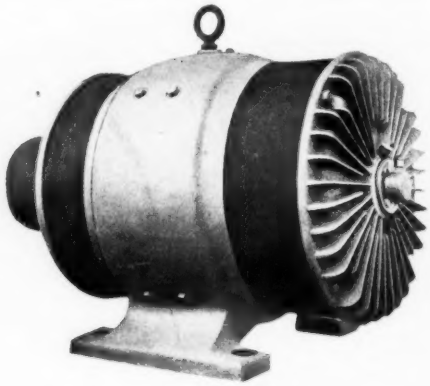

FIG. 2.—TOTALLY-ENCLOSED C.B. MOTOR.

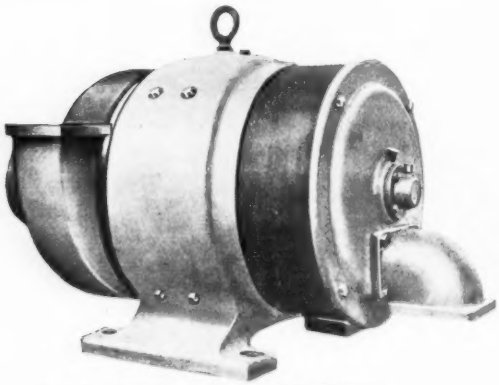

FIG. 3.—PIPE-VENTILATED C.B. MOTOR.

FIG. 4.—ENCLOSED-VENTILATED A.G. MOTOR

FIG 5.—ENCLOSED-VENTILATED A.G.S. MOTOR.

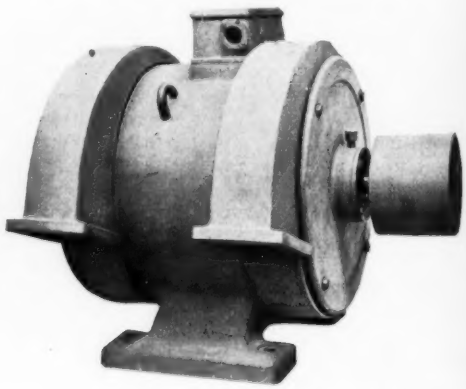

FIG. 6.—DRIP-PROOF A.G. MOTOR.

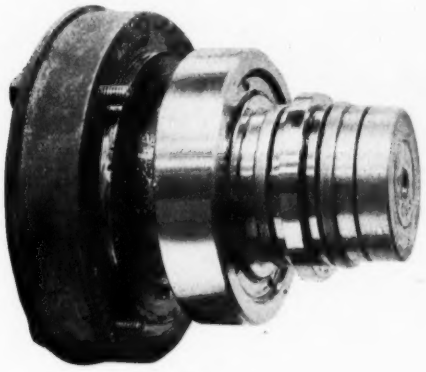

FIG. 7.

outlet pointing upwards, while the Drip-Proof machine (Fig. 6) has both inlet and outlet pointing downwards.

The Totally-Enclosed type (Fig. 2) is similar to the Protected type, but has solid end plates and totally enclosing covers over the circumferential openings.

Ball or Roller Bearings.—All sizes of machine, both D.C. and A.C., are fitted with heavy type ball or roller bearings running in dust-proof housings. These enable the motor to be run in any position without alteration and, in addition, eliminate what experience has proved to be one of the most prolific sources of trouble, leakage or throwing of oil or overfilling of the bearings. For alternating-current motors the superior merits of ball bearings over sleeve bearings are obvious in that no appreciable wear is possible, thus enabling the small air gaps required by Induction Motors to be employed with much greater safety than with a ring lubricated bearing. The number of bearings used throughout the range has been kept down to a minimum to facilitate the stocking of spares. It must be thoroughly understood that the use of ball or roller

FIG. 10.

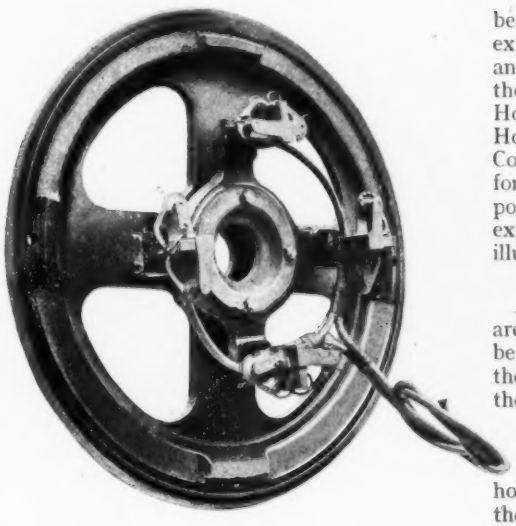

FIG. 11.

bearings on these machines is not in any way experimental; they have stood the severest tests, and in the mounting and selection of the bearings the widest experience has been available. Hoffmann bearings are used throughout, and the Hoffmann Company have co-operated with this Company since the introduction of ball bearings for use with electric motors, so that we are in possession of the fullest and most extensive experience. A ball and thrust bearing is illustrated in Fig. 7

DIRECT CURRENT MACHINES—CLASS C.B.

Armature.—The armature, fan and bearings are shown in Figs. 8 and 16. The fan will be seen to consist of two sections; that nearer the armature draws in air over the surface of the armature and across the field coils, while the other section draws in air through the armature and commutator, the armature being provided with a number of axial holes for the purpose. By this construction the designer has been able to give each part its proper ventilation.

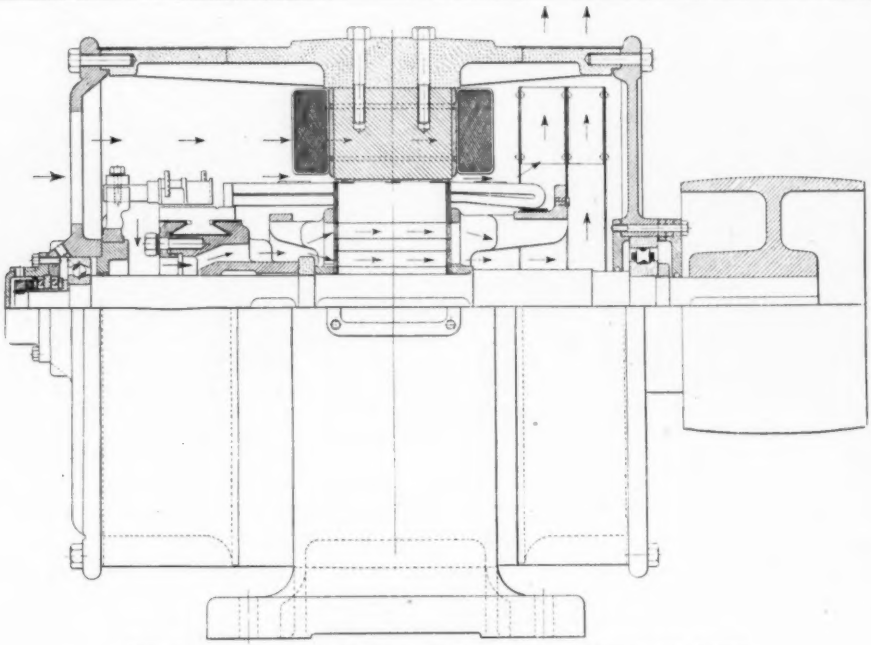

FIG. 8.—DIAGRAMMATIC SECTION OF C.B. MOTOR SHOWING AIR PATHS.

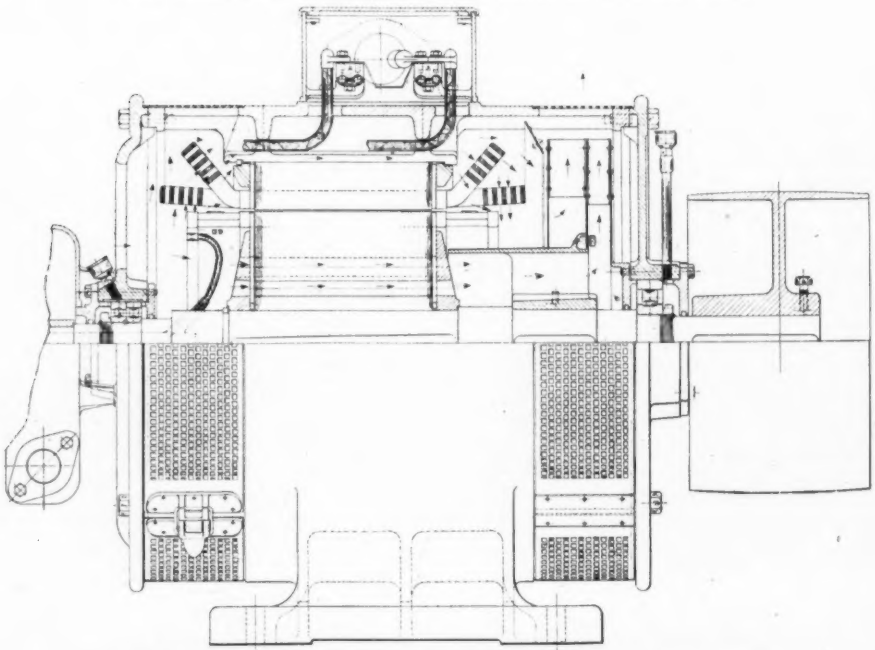

Fig. 9.—DIAGRAMMATIC SECTION OF A.G.S. MOTOR SHOWING AIR PATHS.

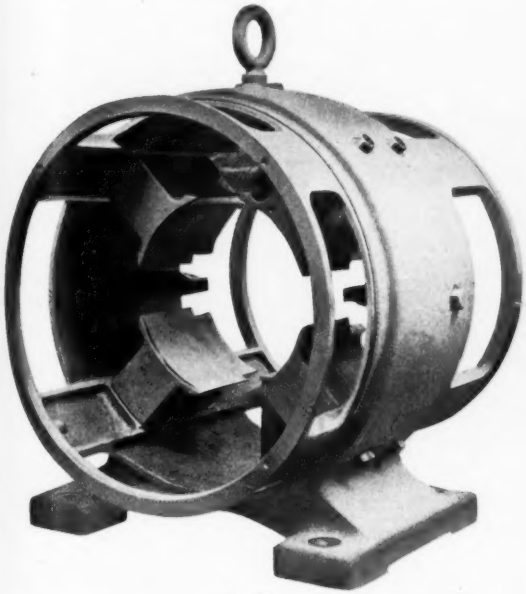

FIG. 12

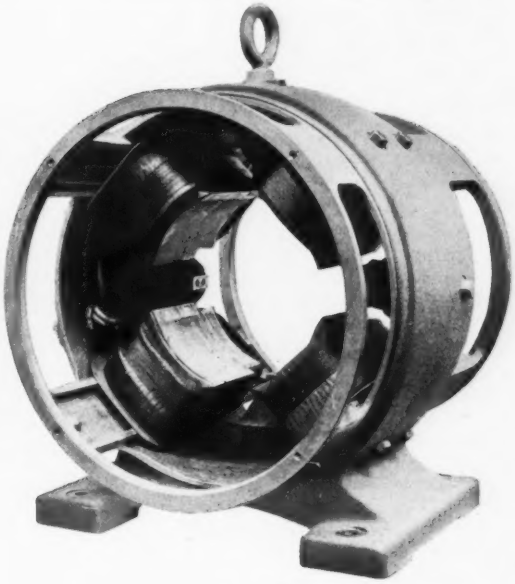

FIG. 13.

The double fan is used on all sizes down to C.B. 9; C.B. 8 and below have only a single fan.

Brush Gear.—The brush holders are shown in Fig. 10, and consist of solid brass castings machined out accurately to size. The spindle is triangular in shape, and thus cannot turn in the rocker. On the smaller sizes the brush holder and spindle are in one piece, while in the larger sizes the holder is bolted to the spindle. As the brush spindle fits into the rocker without shoulders on either side, a line of brushes can be adjusted axially or can be taken out

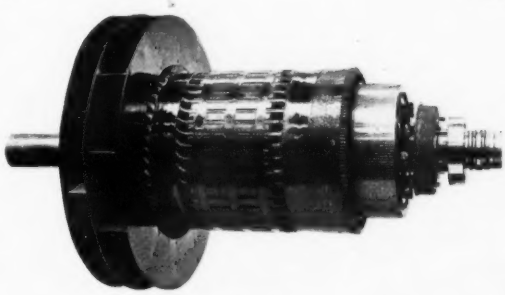

FIG. 14.

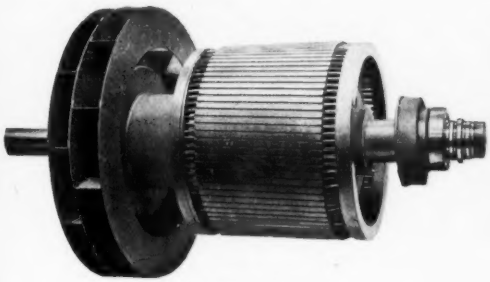

FIG. 15.

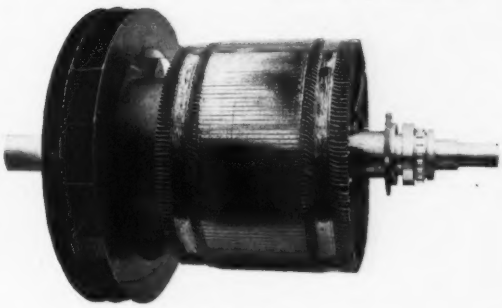

FIG. 16.

of the machine without disturbing the position of the rocker in any way. The brush gear, mounted on the brush rocker, is carried on a seating on the end shield bearing, as shown in Fig. 11. All the leads pass out to a terminal box which can be used with bushes or screwed for pipe connections. Both sides of the terminal box are drilled so that the conduit can be connected to either side, the side not in use being closed with a blank flange.

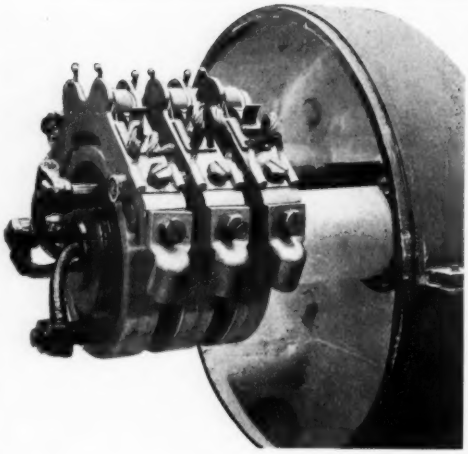

FIG. 17.

Field System.—The magnet frame is of steel, with the poles bolted on as shown in Fig. 12.

The main poles are built up of laminations riveted together between stout end plates, while the commutation poles are of wrought iron with pole pieces secured by screws. As will be seen from Fig. 12, a special feature of the design lies in the fact that the commutation poles extend over only a part of the armature core length and the pole shoes are cut away to give clearance from the commutation pole. This design (which is patented) is a great aid to the proper ventilation of the commutation coils and the field coils, and reduces the leakage between the main and commutation poles.

The field coils are former wound, thoroughly impregnated and taped all over, as will be seen from the assembly in Fig. 13.

ALTERNATING CURRENT MOTORS—CLASS A.G. OR A.G.S.

The English Electric Alternating-Current Motor is of the usual induction type, and is supplied either with slipring or with squirrel-cage rotor; the slipring motor is known as the A.G.S. type, and the squirrel-cage motor as the A.G. type.

Rotor.—A view of the squirrel-cage rotor is shown in Fig. 15. It will be seen that the fan is similar to that used on the D.C. armature, and consists of two parts, one of which draws air axially through axial holes in the rotor and

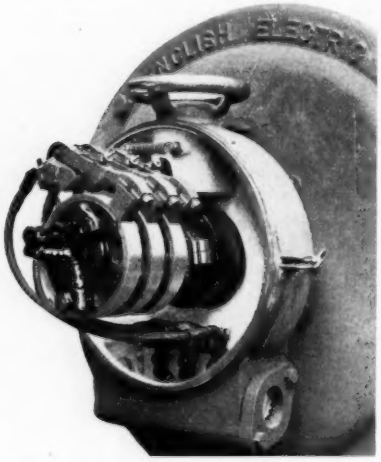

FIG. 18.—STARTING POSITION, BRUSHES DOWN.

S.C. & B.L. DEVICE, (COVER REMOVED).

FIG. 19.—RUNNING POSITION, BRUSHES RAISED AND SLIPRINGS SHORT-CIRCUITED.

FIG. 20.

the other through the air gap and across the back of the stator core (see Fig. 9).

The squirrel-cage rotor consists of stout copper bars with brass end rings cast on. The slots are skewed to give uniform torque and improved starting characteristics.

The slipring rotor is of the usual design with bar or wire winding, the former being illustrated in Fig. 16.

The sliprings are supplied with or without short-circuiting and brush-lifting device, and in all cases are provided with a light stamped sheet steel cover. Each brush holder is controlled by an independent spring. Fig. 17 shows the standard slipring gear for continuous operation. As will be seen from Figs. 18 and 19, the short-circuiting and brush lifting device is of particularly substantial design and is simple and reliable, the mechanism for short-circuiting and brush-lifting is of an entirely fool-proof description.

Stator.—The stator winding in the smaller sizes is of the drop-in barrel type, and in the larger sizes of the hairpin type.

The finished barrel winding is shown in Fig. 20, and this figure also shows the way in which the stator core is bedded directly on projecting bosses on the cast-iron frame. A stator in process of being wound is shown in Fig. 21; the formed coil is to be seen in the foreground, and the method of dropping the winding into the slots is shown in the top left-hand coil. In dropping in the wires the slot lining is first placed in position and the edges bent over so as to form a funnel or guide for the wires; when all the wires are in place the slot lining is bent over and a light wood or fibre key is driven in to close the slot opening. The outhanging portions of the coil are then taped by hand. The coils are impregnated by dipping the whole stator, including its winding, in insulating varnish.

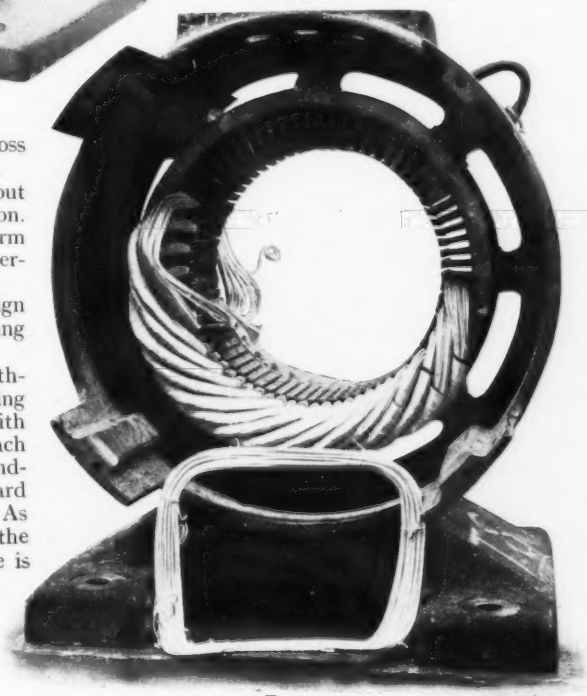

FIG. 21.

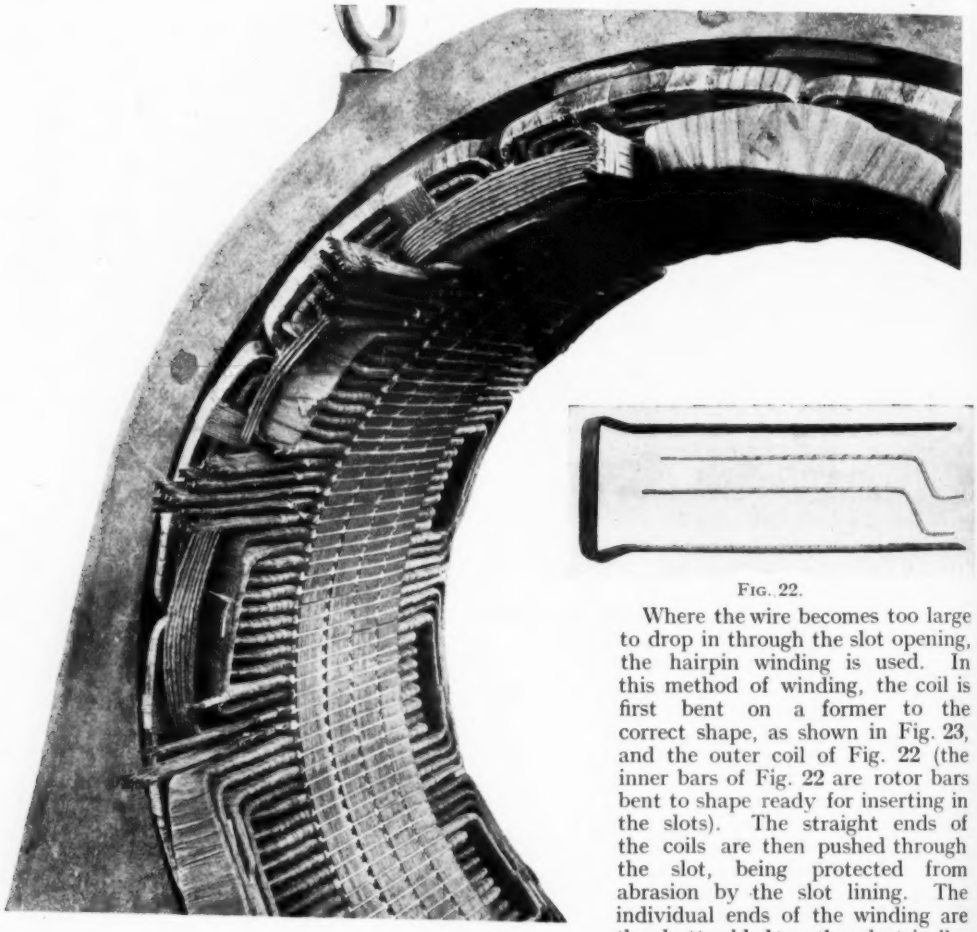

FIG. 24.

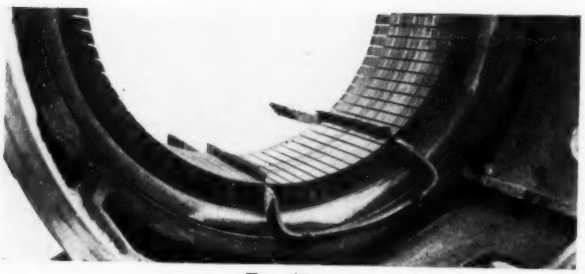

FIG. 23.

FIG. 22.

Where the wire becomes too large to drop in through the slot opening, the hairpin winding is used. In this method of winding, the coil is first bent on a former to the correct shape, as shown in Fig. 23, and the outer coil of Fig. 22 (the inner bars of Fig. 22 are rotor bars bent to shape ready for inserting in the slots). The straight ends of the coils are then pushed through the slot, being protected from abrasion by the slot lining. The individual ends of the winding are then buttwelded together electrically. The process of winding is illustrated in Fig. 24, which shows coils in various stages of completion.

It will be noted that the coil groups are inserted alternately from the right and from the left side of the core.

Figs. 12, 13 and 20 show the type of frame used in the larger sizes of motor, the ends of the projecting arms of the magnet frame being joined together by a circular ring. In the smaller sizes this arm is dispensed with, as will be seen in Fig. 21.

The English Electric Company's Transformers of Small and Medium Size.

These transformers cover a range from 10 K.V.A. to 900 K.V.A. at all standard frequencies. They are of the core type, oil-immersed and self-cooling. The transformers are constructed to give maximum efficiency and also the maximum reliability in operation, and the outstanding feature of the design is the increased allowance of copper and of core iron as compared with that usually provided. This results in decreased losses in the transformer as a whole, and in a correspondingly increased overall efficiency

In the past such a design has not been generally adopted by manufacturers owing to the fact that the extra material increases the cost of production, but in the present instance, by careful attention to other factors that affect the cost, it has been found possible to be more liberal with the active material in the transformer without in any way adding to the selling price. Much attention has been paid to the proportions of the various parts, and in particular to the dimensions and dispositions of the oil channels and spaces in order to secure the most effective circulation of the oil in the tank.

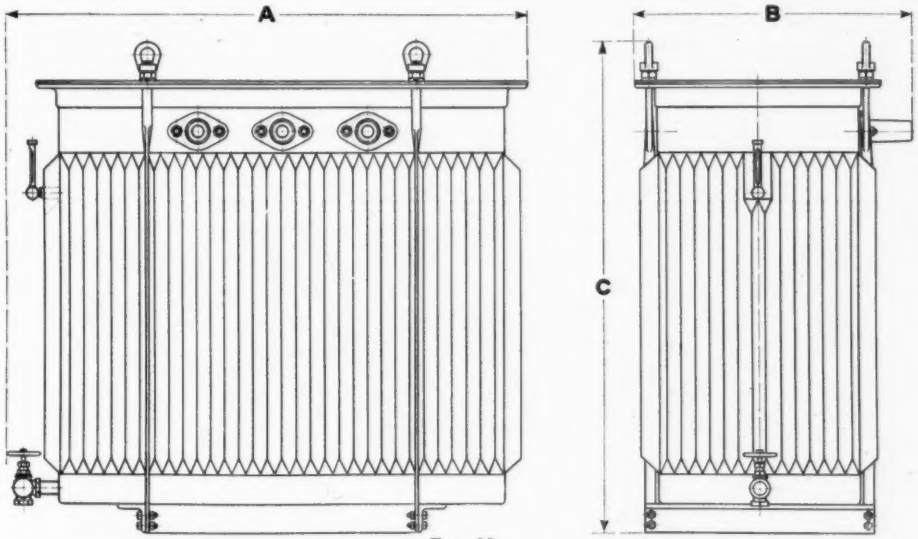

FIG. 25.

DIMENSIONS IN INCHES.

SIZE.	A	B	C H.T. Volts.			SIZE.	A	B	C H.T. Volts.			SIZE.	A	B	C H.T. Volts.		
			3300	6600	10000				3300	6600	10000				3300	6600	10000
C.T. 10	34	18	35	35	37	C.T. 80	39	20	62	65	—	C.T. 300	54½	32¾	74	74	75
C.T. 15	,,	,,	39	41	42	C.T. 80	43	21½	—	—	47	C.T. 350	,,	,,	80	80	81
C.T. 20	,,	,,	43	47	48	C.T. 90	,,	,,	48	48	49	C.T. 400	,,	,,	87	87	88
C.T. 25	,,	,,	50	52	54	C.T. 100	,,	,,	50	51	52	C.T. 450	70	43	74	75	75
C.T. 30	,,	,,	56	58	59	C.T. 110	,,	,,	53	53	54	C.T. 500	,,	,,	78	79	80
C.T. 35	,,	,,	61	64	65	C.T. 120	,,	,,	55	56	57	C.T. 550	,,	,,	82	83	84
C.T. 40	39	20	43	45	46	C.T. 125	,,	,,	57	57	58	C.T. 600	,,	,,	86	87	88
C.T. 45	,,	,,	46	48	48	C.T. 150	,,	,,	63	63	64	C.T. 700	,,	,,	95	96	97
C.T. 50	,,	,,	48	50	51	C.T. 175	,,	,,	68	69	70	C.T. 750	,,	,,	99	100	101
C.T. 60	,,	,,	52	55	56	C.T. 200	54½	32¾	60	61	62	C.T. 800	,,	,,	103	105	106
C.T. 70	,,	,,	57	60	61	C.T. 250	,,	,,	67	67	68	C.T. 900	,,	,,	111	113	115

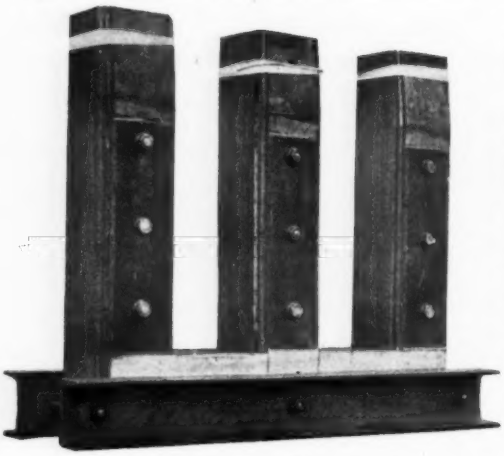

FIG. 26.

The increased section of the copper and of the iron has the additional advantage of improving the regulation of the transformer.

Special attention has been paid to simplicity of design, and to standardisation of parts, with a view, not only to economy in manufacture, but also to facility in stocking of parts and for giving short times of delivery. The question of standardisation of transformers, and particularly of transformer parts, is a difficult and complex one, since it is practically impossible to standardise one most important item, viz., the coils or windings. In the case of almost all other classes of electrical plant the voltage at which a machine is to work is clearly defined, and is one of a small number of standard voltages, but in the case of a transformer this is not so, owing to the many combinations of voltage possible and the difficulty of forecasting what ratios of transformation are likely to be most

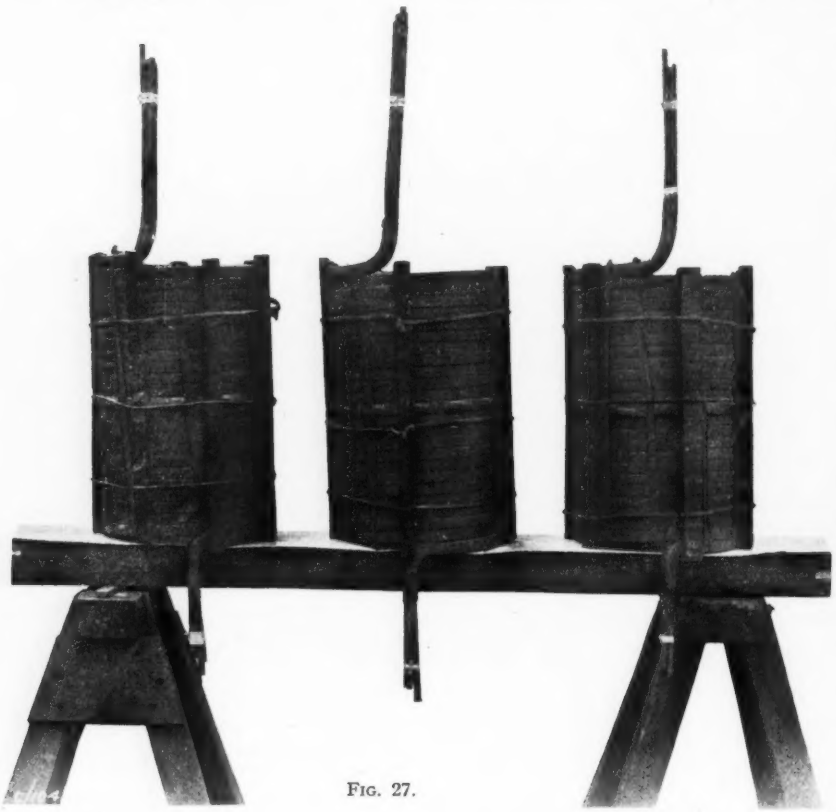

FIG. 27.

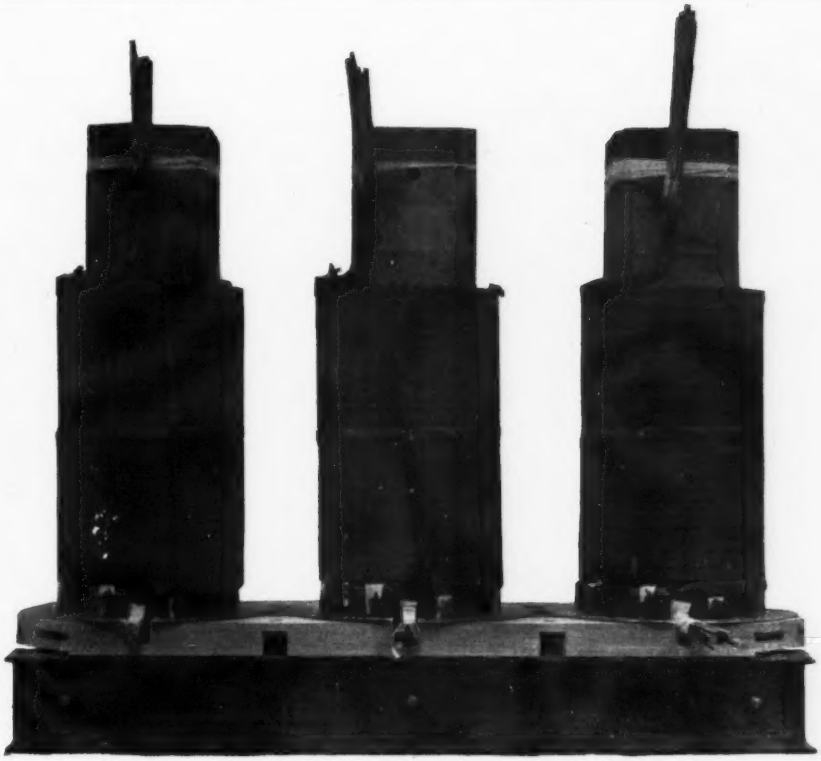

FIG. 28.

in demand. As a matter of fact, it is the transformer with its flexibility with respect to voltage, which is the variable link that permits of the voltages of other machines, generators, motors, etc., being readily standardised. For this reason, the best that can be done is to adopt standard tanks, standard cores, standard insulating tubes, collars, and so on, and to wind the coils as required as rapidly as possible, and then to fit the specially wound coils to the other parts which have been standardised. This is the method that has been adopted as the underlying principle in the construction of the English Electric Transformers here described. In the standardisation of these parts, the transformers have been divided into groups, largely in accordance with their output; all the above-mentioned parts are made absolutely standard for each individual group, and the only variable inside a group is the length of core leg, and, consequently, the overall height of the transformer. Fig. 25 and the accompanying dimension table, which gives the overall dimensions of the complete range of 50-cycle transformers manufactured in this type, illustrate the application of these principles.

General Description of the Transformer.—For all sizes the tank is of corrugated welded sheet steel, and is fitted with a drain cock or plug and an oil gauge. Substantial lifting eyes are provided, but the transformer is not normally supplied with wheels or runners unless these are specially ordered by the purchaser.

The core is built up of best alloyed high resistance sheet steel, each plate being insulated on one side with material which does not deteriorate with heating. The ageing of the steel used is practically negligible. One of these cores in course of erection is shown in Fig. 26.

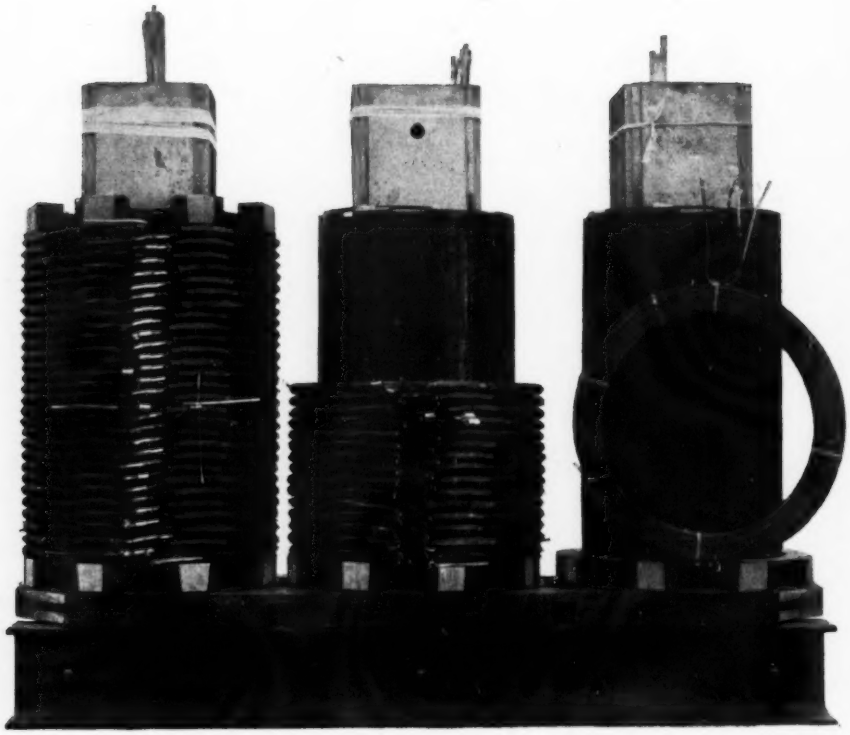

FIG. 29.

The windings are distributed on the three cores, and the magnetic circuits are coupled by yoke pieces which are interleaved with the cores.

Circular, former-wound coils are used. A set of low tension coils, held together by means of binding strips, which are removed before the coils are assembled, are shown in Fig. 27. The coils are assembled to form two concentric cylinders, of which the outer cylinder is the high tension, and the inner cylinder the low tension winding. The two windings are separated by a stout insulating shield with an oil space on each side, except in the sizes for low voltages and low outputs, where the high tension coils are wound directly on to the low tension coils. Distance pieces are provided between the low tension winding and the core in all sizes to allow free circulation of the oil. Fig. 28 shows three low tension coils in position.

The high tension windings are sectionalised to reduce the voltage between the turns in adjacent layers to a low value. Movement of the coils is prevented by firmly clamping them together at the top and bottom by hard wood pieces, which can be seen in Fig. 29. This illustrates a transformer with all its low tension coils, insulating shields, and distance pieces in position on the core. In addition to these, on the left-hand leg of this core will be seen a sectionalised high tension winding, with its

hard wood clamping pieces on the top and bottom, while on the other two legs the clamping pieces will be seen only on the bottom. On the middle leg half of the high tension windings are in position, while the right-hand leg supports one high tension coil in a vertical plane to give a view of the coil as it is seen from above.

Fig. 30 gives a view of the complete internal portion of the transformer, ready for insertion in the tank.

The terminals for voltages above 1,000 are of porcelain. They are fixed at the side of the tank, unless otherwise specified. The stalks of the terminals are made oil-tight by means of oil-proof rubber washers. Terminals for voltages below 1,000 are inside the tanks above the oil level, and customers' leads are brought into the tank through bushings. Unless otherwise specified, three high tension and three low tension terminals only are fitted, but if tappings are required, they can be provided for up to four

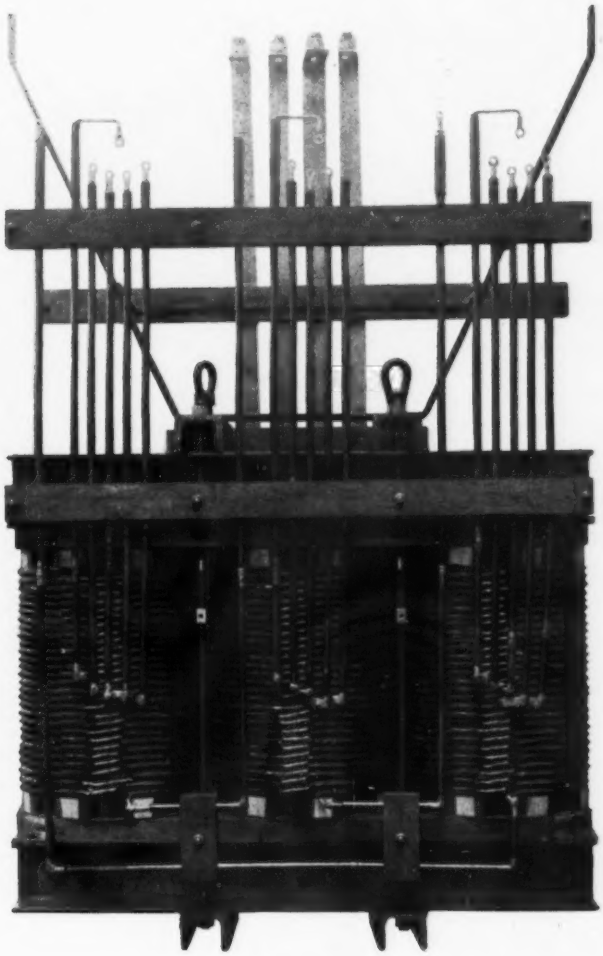

FIG. 30.

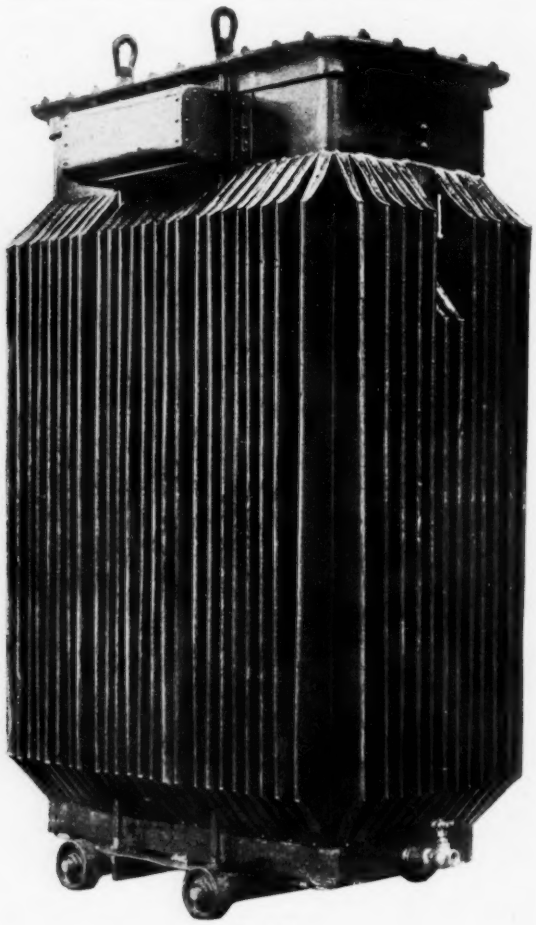

FIG. 31.

additional voltages per terminal. These tappings, when supplied, are brought out to studs below the oil level, and the required connections can be made by moveable links. The neutral point of the low tension winding is brought out to a suitable terminal, and, if specially ordered, an earthing device can also be fitted. Fig. 31 shows a complete transformer.

The oil is supplied by the Company, and is ordinarily forwarded in sealed drums. The transformer is dried out before despatch, and instructions are sent with it for treating the oil before putting the transformer on load, but in no case are any elaborate arrangements necessary for drying out either the oil or the transformer on site.

These transformers can be supplied to run in parallel with one another, and in this case they will share the load in proportion to their rated outputs within $\pm$ 10 per cent.

The English Electric Company also manufactures transformers of larger outputs and a large number of these have been in successful operation for many years. The design of these larger transformers differs in many respects from the design of the transformers referred to above, and will be described in a later number of this Journal.

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